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FINAL REPORT

DEVELOPMENT OF A QUASI-DOPPLER VHF RADIO DIRECTION FINDER SYSTEM FOR AIR TRAFFIC CONTROL

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FINAL REPORT

DEVELOPMENT OF A QUASI-DOPPLER VHF RADIO DIRECTION FINDER SYSTEM FOR AIR TRAFFIC CONTROL

by

Z.A. Krajewski, Project Leader

Bayly Engineering Ltd.,
167 Hunt St., Ajax, Ontario

August 1982

Un sommaire en francais de ce rapport est inclus avant la Table de Matières

The contents of this report reflect the views of the Contractor and not necessarily the official views or policies of Transport Canada

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17. **Abstract**

A new radio direction finder was developed, based on the Quasi-Doppler principle, to provide an up-to-date Canadian model for use in Civilian air traffic control in the band of 117.5-136.5 MHz. The development applies certain novel features such as real-time phase comparison and digital processing of the bearing data intended to improve the system accuracy. A technical description of the new equipment is given, together with a series of reports on the development of critical areas. Test results are shown on the performance of the experimental prototype, as tested at the contractor's field test site. Following the completion of this development phase, the prototype is to be installed at an airport for operational evaluation.

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17 Résumé

Le développement d'un nouveau radiogoniomètre, basé sur le principe Quasi-Doppler, a été entrepris afin de fournir un modèle canadien plus récent de radiogoniomètre destiné au contrôle du traffic aérien des aéroports civils dans la bande 117.5-136.5 MHz. Certaines nouvelles caractéristiques sont appliquées telles que la comparaison de phase en temps réel et le traitement numérique de l'angle afin d'améliorer la précision du système. Une description technique du nouvel équipement est donnée ainsi qu'une série de rapports sur le développement des secteurs critiques. Sont également inclus des résultats de tests effectués sur le prototype expérimental au champ de test du contracteur. Une fois la phase de développement complétée, le prototype sera installé dans un aéroport afin d'en faire une évaluation opérationnelle.

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SUMMARY

This report covers the technical aspects of development and prototype performance of a VHF Doppler Direction Finder developed, designed and constructed by Bayly Engineering Ltd., under the contract no. 1SD 79-00129 for the Transportation Development Centre of Transport Canada.

The program was initiated with the intention to provide a Canadian made RDF equipment capable of assisting air traffic control on Canadian airports. The design objectives were set to overcome certain known deficiencies associated with the equipment in use up to this time. For this purpose, a study was made of the problem areas and an unsolicited technical proposal was submitted by the Company outlining the design concepts proposed to resolve the problems. This proposal was incorporated into the Contract. The early development effort was concentrated to prove that the problems can be resolved. This part was followed by design of the more conventional sections and finally by the construction and trouble-shooting of the entire DF system.

The report presents a description of the newly developed equipment, the technical specifications and a review of the new features. Detailed technical descriptions are included of circuits and sub-systems developed for the problem areas. (Certain earlier proofs of these individual papers may have first appeared as appendices to the interim administration progress reports). Finally, the test results are shown as obtained on the prototype of the Company's field test site, prior to installation at an airport site assigned by Transport Canada.

SOMMAIRE

Le présent rapport traite des aspects techniques relatifs au développement et à la performance du prototype du Radiogoniomètre Doppler VHF conçu, mis au point et réalisé par Bayly Engineering Ltée en vertu du contrat no. 1SD 79-00129 pour le Centre de développement des transports.

Le programme à été mis sur pied afin de permettre la conception d'un équipement de radiogoniometre canadien susceptible de venir en aide aux contrôleurs aériens des aéroports canadiens. Les objectifs fixés lors de sa conception visaient à surmonter certaines des difficultés éprouvées avec l'équipement utilisé jusqu'à maintenant. A cette fin, une étude des secteurs-problème à été entreprise par la compagnie, et elle a pris l'initiative de présenter les grandes lignes des solutions proposées pour résoudre ces problèmes. Cette proposition a été incorporée dans le contrat. Cette recherche a été effectuée afin de montrer que les problèmes peuvent être résolus. Suivent les sections plus conventionnelles et finalement, la mise en oeuvre et les techniques de dépannage du système de radiogoniométrie au complet.

On trouve dans le rapport une description du nouvel équipement mis au point incluant les spécifications techniques et une révision des nouvelles caractéristiques. On y trouve également des descriptions techniques détaillées des circuits et des sous-systèmes mis au point pour les secteurs-problèmes. (Il se peut que certaines d'entre elles aient déjà été annexées aux rapports intérimaires de l'état de la situation). On y trouve finalement les résultats de test effectués par la compagnie sur le prototype avant qu'il ne soit installé sur un site aéroportuaire assigné par Transports Canada.

TABLE OF CONTENTS

Page

1. INTRODUCTION 1
   1.1 Background 1
   1.2 The New Doppler DF System 1

2. NOVEL DESIGN APPROACHES 3
   2.1 Inherent Problem Areas 3
   2.2 Differential Sampling of Phase 3
   2.3 Fundamental Advantages 4
   2.4 Receiver Channel Commutation 5
   2.5 Adjacent Channel Interference 5
   2.6 Immunity from Site Errors 6
   2.7 Cancellation of Group Delay Error 6
   2.8 Interference Flicker 6
   2.9 Separate Audio Channel 7

3. GENERAL DESCRIPTION

   3.1 Introduction 8
   3.2 Simplified System Outline 8
   3.3 Principle of Operation 10
   3.3.1 DF Bearing 10
   3.3.2 Transmission of Audio and DF Data 12
   3.3.3 Synthesized Local Oscillator 13
   3.3.4 Emergency Channel 13
   3.3.5 Built-in Test Facilities 14
   3.4 Installation Configuration 14
   3.5 Equipment Complement 14
   3.5.1 Antenna, 16 Element 14
   3.5.2 Receiver Unit 14
   3.5.3 Interconnection Cable Set 15
   3.5.4 Control/Display Unit 15

4. SPECIFICATIONS (PRELIMINARY)
   QUASI-DOPPLER DF SYSTEM 300 19
   4.1 DF System 19
   4.2 Audio Monitoring Option 21
   4.3 Emergency Call Option 22
   4.4 Antenna Simulator Test Injection Option 22
   4.5 Environmental 23

5. ANTENNA SUB-SYSTEM 24
   5.1 Antenna Design Approach 24
   5.2 Measurements of Dipole Impedance and Interaction 24
   5.3 Soft Switching Technique for Reduction of Adjacent Channel Interference 28
   5.4 Unit Dipole Switch - Circuit Diagram 34
   5.5 Mechanical Construction of the Antenna Array 35
   5.6 Polar Patterns Obtained with Antenna Array 38
   5.7 Test Injection Circuit 52

TABLE OF CONTENTS (Cont'd)

Page

6. RECEIVER AND BEARING PROCESSOR 55
- 6.1 DF Receiver Front End Prototype 55
- 6.1.1 Scope 55
- 6.1.2 Composition 55
- 6.1.3 The RF Section 55
- 6.1.4 Mixer 57
- 6.1.5 The IF Section 57
- 6.1.6 The LO Buffer 58
- 6.1.7 Conclusion 58
- 6.2 Tuned Amplifier for 30 MHz and 2.2 MHz for ADF System 60
- 6.3 Development of IF Amplifiers 64
- 6.4 Development of Mixer and Phase Detector 67
- 6.4.1 200 kHz Mixer 67
- 6.4.2 Phase Detector 67
- 6.5 Development of a 200 kHz Compression Amplifier 69
- 6.6 DF Twin Channel Receiver Signal and Noise Level Chart 72
- 6.7 Antenna Unit and Receiver Block Diagram 74
- 6.8 Frequency Synthesizer 74
- 6.8.1 Design Philosophy 74
- 6.8.2 Breakdown of Development Tasks 77
- 6.8.3 Specifications 78
- 6.9. Bearing Processor 81
- 6.9.1 Data Acquisition Module 82
- 6.9.2 DFT Processors 82
- 6.9.3 Clock and Timing Module 86
- 6.9.4 Microprocessor Module 86
- 6.9.5 Angle and Averaging Module 86
- 6.9.6 Summary of Bearing Processor Concept 86

7. DATA LINK, CONTROLS AND DISPLAY 89
- 7.1 The Concept 89
- 7.1.1 Conversion and Transmission 89
- 7.1.2 Reception and Data Recovery 89
- 7.1.3 Channel and Bearing Display 90
- 7.1.4 Summary 91
- 7.2 Improvements and Modifications 92
- 7.2.1 Security of Critical Data and Control Functions 92
- 7.2.2 Local/Remote Control of the Receiver 92
- 7.2.3 Automatic Emergency Operations 93
- 7.2.4 Displays 93
- 7.2.5 Controls 93
- 7.3 Direct Access Dialing Frequency Selection 95
- 7.4 Development of a Circular Bearing Display 97
- 7.5 Final Arrangement of Controls 99

TABLE OF CONTENTS (Cont'd)

Page

8. SYSTEM OPERATION 100
    8.1 Evaluation of Sub-systems and Functional Blocks 100
    8.2 DF Field Trials 101
    8.3 Field Test Results 109

9. CONCLUSIONS AND RECOMMENDATIONS 110
    9.1 Completion of the Development Phase 110
    9.2 Follow-up Stages of Work 110

LIST OF FIGURES

		Page
Figure 3.2.1	Simplified System Outline	16
Figure 3.2.2	Principle of Operation	17
Figure 3.4.3	Quasi-Doppler DF System - Typical Installation Configuration	18
Figure 5.2.1	Dipole Impedance - Free Space	26
Figure 5.2.2	Dipole Impedance on Ground Plane	26
Figure 5.2.3	Effect of Adjacent Dipoles when Terminated into 75 Ohms	26
Figure 5.2.4	Effect of Removing Ground Rods	27
Figure 5.2.5	Termination of Adjacent Dipoles by Short Circuit	27
Figure 5.2.6	Termination of Adjacent Dipoles by Open Circuit	27
Figure 5.3.1	Output Spectrum with Square Wave Switching	30
Figure 5.3.2	RF Switch	30
Figure 5.3.3	Output Spectrum with Square Wave Switching	31
Figure 5.3.4	Output Spectrum with Square Wave Switching	31
Figure 5.3.5	Attenuation/Current Response for RF Switch	32
Figure 5.3.6	Pre-distorted Soft Switch Waveform	33
Figure 5.3.7	Output Spectrum with Pre-distorted Waveform	33
Figure 5.4.1	Unit Dipole Switch Circuit Diagram	34
Figure 5.5.1	Pictorial View of Antenna Assembly	36
Figure 5.6.1	Doppler Dipole No. 1 - Phase Relative to Dipole No. 16	39
Figure 5.6.2A	137 MHz Azimuth Polar Pattern	40
Figure 5.6.2B	127 MHz Azimuth Polar Pattern	41
Figure 5.6.2C	117 MHz Azimuth Polar Pattern	42
Figure 5.6.3A	137 MHz Azimuth Polar Pattern	43
Figure 5.6.3B	127 MHz Azimuth Polar Pattern	44
Figure 5.6.3C	117 MHz Azimuth Polar Pattern	45
Figure 5.6.4A	137 MHz Phase Difference Polar Pattern	46
Figure 5.6.4B	127 MHz Phase Difference Polar Pattern	47
Figure 5.6.4C	117 MHz Phase Difference Polar Pattern	48
Figure 5.6.5A	137 MHz Phase Difference Polar Pattern	49
Figure 5.6.5B	127 MHz Phase Difference Polar Pattern	50
Figure 5.6.5C	117 MHz Phase Difference Polar Pattern	51
Figure 5.7.1	Test Signal Injection Block Diagram	54
Figure 6.1.1	2nd RF Filter - Amplitude Response	56
Figure 6.1.2	2nd RF Filter - Phase Response	57
Figure 6.1.3	1st IF Filter - Amplitude Response	57
Figure 6.1.4	1st IF Filter - Phase Response	58
Figure 6.1.5	Test Circuit for Future Analysis	59
Figure 6.2.1	30 MHz DF Amplifier Frequency Response	61
Figure 6.2.2	30 MHz DF Amplifier with AGC Circuit Diagram	62
Figure 6.2.3	30 MHz DF Amplifier AGC Response	63
Figure 6.3.1	30 MHz IF Amplifier : Gain = 32 dB	65
Figure 6.3.2	30 MHz IF Amplifier : Gain = 10 dB	65
Figure 6.3.3	2.2 MHz IF Amplifier : Gain = 32 dB	66
Figure 6.4.1	Phase Detector	68
Figure 6.4.2	200 kHz Mixer	68

LIST OF FIGURES (Cont'd)

Page

Figure 6.4.1 Phase Detector 68
Figure 6.4.2 200 kHz Mixer 68
Figure 6.5.1 200 kHz Amplifier Limiter Circuit Diagram 70
Figure 6.5.2 Gain & Phase Characteristics 71
Figure 6.6.1 Doppler DF Twin Channel Receiver - Signal and Noise Level Chart 73
Figure 6.7.1 Doppler Radio DF Antenna Unit Block Diagram 75
Figure 6.7.2 DF Receiver Block Diagram 76
Figure 6.8.1 Frequency Synthesizer Block Diagram 80
Figure 6.9.1 Bearing Processor Block Diagram 81
Figure 6.9.2 Block Diagram of Data Acquisition 83
Figure 6.9.3 Data Acquisition Timing 83
Figure 6.9.4 DFT Processor Module 84
Figure 6.9.5 Clock of Timing Module 84
Figure 6.9.6 Microprocessor Module 85
Figure 6.9.7 Angle and Averaging Unit 85
Figure 6.9.8 Bearing Data Processor Block Diagram 87
Figure 6.9.9 Algorithm Flow Graph 88
Figure 7.1 Data Transmission Link (FSK Mod and Demod) 91
Figure 7.2 Control and Display Console 94
Figure 7.3.1 Flowchart for Channel/Frequency Selector in the Receiver 96
Figure 7.4.1 Circular Display of Bearing (5° Resolution) 98
Figure 7.5.1 Operator's Control/Display Panel, Controls and Indicators 99
Figure 8.2.4.1 Field Test Site 103
Figure 8.2.4.2 Plan of Test Site 104
Figure 8.2.5.1 Field Test - Instrumental Bearing Accuracy 106
Figure 8.2.8.1 Field Test - Dipole Spacing Error 107
Figure 8.2.7.1 Field Test - Instrumental Bearing Accuracy 108

LIST OF APPENDICES

Appendix 1 DF Instrumental Accuracy Test 111
Appendix 2 DF System Field Test - Dipole Spacing Error 112
Appendix 3 DF Instrumental Accuracy Test (Final Test) 113

1. INTRODUCTION

1.1 Background

Early Doppler DF, dating back to the Second World War, used a physically rotating antenna pair producing a signal which was frequency modulated at the rate of the rotation of the antenna. A phase of this FM is related to the angular position of the target and can be detected with reference to a given azimuth point, e.g. the North. In later developments, antenna rotation was replaced by sequential switching of a series of fixed dipoles arranged in a circular array.

The advantage of the Doppler principle lies in the relatively large aperture of the antenna which is of the order of one to several wavelengths. The larger the relative aperture, the smaller are the errors due to local reflections of the received signal. Large apertures, on the other hand, necessitate increased numbers of switched elements and a more elaborate commutating system, resulting in higher costs. For navigational aids, it is usual to compromise, giving the required bearing accuracy of 1° or better at minimum cost.

1.2 The New Doppler DF System

The new Doppler DF System is designed for fixed land-based installation, to operate in the Air Traffic Control range 117.5 - 136.5 MHz. The system comprises a stationary circular antenna array, a remote receiver unit and a local display/control unit. The antenna and the receiver unit are connected with a set of RF cables of up to 50 m in length and the receiver is linked to the display/control unit by means of a standard 4-wire telephone line.

Two optional features are available with the main system:

1) Facility to demodulate the VF intelligence of the incoming signal (AM detectors) and to transmit it to the display/control unit.

2) Emergency call facility, operating on 121.5 MHz or 243 MHz, to override temporarily the normal operation of the system.

The design is modular in order to ensure good maintainability and to provide a basis to future extensions of the system for applications in the marine band (156-164 MHz) and the military ATC range of 220-400 MHz.

The coastal navigation requirements differ from those for air traffic control in that FM detection is required. The audio facility may be omitted as an option with a reduction of cost. Although different frequency bands are used for the two applications, the system design remains the same, the difference being covered by changing antenna dimensions and replacing certain plug-in filter and oscillator modules.

2. NOVEL DESIGN APPROACHES

2.1 Inherent Problem Areas

Doppler DF Systems present problems inherently bound with their method of operation:

1) The bearing tends to fluctuate with frequency modulation of the signal either by the superimposed intelligence or by noise;

2) The detection of modulated intelligence becomes difficult in the presence of the simulated antenna rotation switching.

3) The response time is not negligible, since multiple rotations of the antenna have to be integrated to evaluate the DF data.

4) Intermodulation products are generated at the antenna commutation interface. They appear as FM sidebands and may have enough amplitude to splash over into the adjacent channels.

The new design is aimed at improving the solutions to the above problems by introducing several novel approaches.

2.2 Differential Sampling of Phase

The Doppler antenna consists of a number of vertical dipoles tuned to the top of the frequency band and spaced equally in a circle. All the dipoles are connected with equal length cables to the commutator located in the centre hub. In the new design, two adjacent dipoles are sampled simultaneously, the pair being switched round the circle at a rate set by the commutation generator. The voltages induced in the sampled pair remain almost constant but their relative phase undergoes cyclical variation as the switching progresses through 360°. This phase can be measured continuously after the two signals are processed through two identical receiver channels, each consisting of RF amplifiers, frequency converters and i.f. stages.

The comparator operates at the final intermediate frequency and produces an output of a stepped waveform superimposed over a sine function. It is the positive-slope zero crossing of this waveform which determines the angular position of the target.

To determine this position accurately, the Phase Comparator output must be processed to reduce it to a pure sine wave and then its phase must be compared with that of North reference signal which is supplied directly from the commutation generator. A fine North setting adjustment is provided by the Reference Control. Employing a special Fourier Analysis processor, a digital bearing readout is obtained in steps of 0.1°, indicated digitally on the Remote Bearing Indicator. The bearing readout can be reversed by 180° by operating the QDR/QDM Control Line. The selected mode is also indicated by a LED readout underneath the angle data. A variable integration constant is provided in the Bearing Processor, enabling the operator to set an optimum compromise between the signal quality and speed of response.

2.3 Fundamental Advantages

By sampling two instead of one dipole, the restrictions are removed on the aperture of the array - there being no ambiguity of bearing as the diameter becomes larger than the wavelength. The same system design may be used with different sizes of arrays, say with 16 elements and 32 elements. The choice depends on a compromise between the cost of the antenna and the immunity to local reflection errors. For a bearing accuracy of ±1.5°, 16 elements are required on a circle of approximately 1.5 diameter.

Speed of commutation is no longer critical. There is no need to ensure a frequency deviation large enough in comparison with the stability of the carrier. The only criterion is that of the bearing response time. A rotation frequency of about 100 Hz would provide a bearing reading averaged over 8 cycles in 0.1 second. A low commutating frequency has the advantage of less interference with the audio reception. Furthermore, the splash-over of intermodulation products into the adjacent frequency channels is also reduced.

The two i.f. channel voltages are similar in amplitude and contain equal percentages of AM or FM and an equal share of atmospheric noise. By measuring their relative phase, any modulation or noise effect is reduced to negligible proportions. Moreover, the phase comparator need not be precise, or even linear, since it is the cyclical waveform of the phase output which contains the azimuth information and not its amplitude.

The phase comparator operates throughout each period of dipole pair sampling so that there is no waste of real time in receiving the azimuth information. The system is thus more immune to noise and pulse interference.

The system is capable of expanding to a wide band operation by adding lower frequency ranges with the same antenna rray and without substantial loss of sensitivity. This can be simply done by sampling antenna pairs spaced two or three apart, etc., so as to maintain an optimum phase difference at increased wavelengths. The limit of spacing is obviously set by the diametrical pair of dipoles.

2.4 Receiver Channel Commutation

The accuracy of phase measurement with a twin channel receiver depends on the precision with which the two channels can be matched in phase over the bandwidth and over their dynamic range. This precision depends largely on the type of filter used in the final i.f. stages.

The total number of switching steps for one antenna rotation becomes 2n where n is the number of antenna elements. The phase fluctuations due to channel mismatch are hence smoothed out together with the progression of antenna steps, giving a final phase waveform approximating a sine wave.

2.5 Adjacent Channel Interference

Commutation of the antenna elements is conventionally done with a diode matrix. In this case each antenna element must be able to select one of three paths:

i Input of receiver channel 1

ii input of receiver channel 2

iii a dummy load

The matrix is programmed to advance the sampled pair of elements step by step around the circle, each step operation being performed first with normal and then with reversed receiver channels.

The switching function of the antenna elements is very critical. Multiple sideband spectra of intermodulation products can be caused by abrupt non-linearities. Unless suitably suppressed, the sidebands can splash over into the adjacent frequency channels, causing false alarms in the presence of strong adjacent signals. By means of 'soft' switches, the switching function is shaped for optimum splash sideband suppression within the desired bandwidth.

The antenna commutation matrix is in modular form, the basic module being equivalent to an 8-pole, 3-way switch ro provide scanning for an 8-element antenna. By interconnecting two or four such modules, scanning can be provided for antennas of 16 or 32 elements respectively.

2.6 Immunity from Site Errors

The size of the antenna is decided by the site conditions and the desired accuracy of bearing in the presence of stationary or moving objects in the vicinity of the antenna tower. The immunity from errors caused by reflections from such objects is a function of antenna aperture and hence the number of antenna elements. While 16 elements (antenna array diameter of 1.5) may be satisfactory for airports with a clear site, a 32-element antenna (diameter of 32) will be necessary for harbours or more built-up areas.

The basic design of the Doppler DF remains the same regardless of the antenna choice as long as the numbers of the antenna elements remain in a simple ratio. In the proposed design, systems of 8, 16 and 32 elements can be assembled from the same basic blocks. In this way, the cost and size of the antenna can be matched to the required system accuracy.

2.7 Cancellation of Group Delay Error

Direction Finders with rotating antennas have to be compensated for the zero reference offset resulting from a finite time the signal takes to travel through the receiver. Conventionally, this is done by adjusting the phase of the reference voltage from the generator of the antenna commutation frequency. This compensation can only be true at the centre frequency of the final i.f. filter. It can seriously deviate from the required value if the transmitter frequency is drifting either due to its stability or the movement of the target. An improvement may be reached by tracking the transmitter with the AFC, especially when the transmitted spectrum is symmetrical or when a strong carrier is present.

2.8 Interference Flicker

It happens sometimes that the interference picked up on a channel frequency is synchronous with the scan of the Doppler antenna array. In this case, the operator may not recognise the existence of an error in the bearing readout with possible grave consequences. This can be avoided by introducing a small shift in the scan frequency which will then cause the bearing to fluctuate, giving an indication of the full extent of the error.

Doppler type systems of older design were not capable of varying the scan frequency since such a change resulted in altering the group delay of the final scan filters. The new design employs a digital processor to filter the bearing output and hence makes the reading independent of scan frequency. It is believed that this method is the only one offering this advantage.

2.9 Separate Audio Channel

A separate antenna, located at the electrical centre of the array is connected to another receiver channel tuned to the same frequency as the two Doppler channels. The i.f. portion is provided with AGC and connects to an AM demodulator. Re-radiation of the commutation pulses from the DF dipoles is reduced by keeping this antenna separate and somewhat elevated with respect to the plane of the array. The audio output of this receiver can be monitored in the remote unit and is further available for transmission to the local unit.

Since the FM cancellation for DF no longer depends on the signal from the centre antenna, the entire audio channel can be left out if this facility is not required.

3. GENERAL DESCRIPTION

3.1 Introduction

Quasi-Doppler DF System 300 (Frontispiece) is a compact, fixed equipment set, designed for passive radio direction finding. It is particularly suitable for use in conjunction with air traffic control (ATC) operations at small airports. With low traffic density, it can be used at medium sized airports.

The system operator may select one of ten numbered and pre-tuned receiving channels (or an emergency channel) in the VHF band 117.5 to 136.5 MHz. Additionally, any single channel in the band can be selected by frequency. The bearing readout is displayed in both numerical and analog form.

Except for the operator controls, there are no moving parts. The antenna structure and three units comprise the essential system. In the units, a modular approach (power supply modules, plug-in cards, etc.) has been used wherever practicable.

3.2 Simplified System Outline (Fig. 3.2.1)

The 300 system is operationally controlled from the 'operator's control and display panel' located in the ATC tower. This control location is determined by the 'local/remote' switch when set to the 'remote' position. The 'local' position of this switch is used during maintenance work only.

The 300 system ATC tower equipment is linked to the antenna/receiver site equipment through a standard, 4-wire telephone cable. All necessary data conversion and interfacing functions are performed at each end of the cable.

The stationary antenna consists of sixteen dipoles equally spaced and arrayed around a horizontal circle. The purpose of the array is to simulate a step rotation through 360° of a single dipole pair.

A single 'rotation' or 'revolution' of the simulated pair is made by means of sixteen sequential samplings of the sixteen dipole outputs whereby each dipole forms one-half of a given pair.

Since, for each dipole pair sampling, a different pair is used, the simulated pair moves around the circle in sixteen steps through 360°. However, the error introduced by the diameter of the circle is negligible.

The dipole pair sampling sequence and timing originate with a 'scan clock' pulse output from the 'bearing processor' block. This pulse clocks the 'scan logic' which, operating through driver stages, causes the 'antenna switching' to operate in the correct scanning (sampling) sequence and timing (360° x 100 Hz).

When the antenna dipole array has been sited and assembled, it is necessary to determine a North reference point. A North marker, generated in the 'bearing processor' can then be adjusted in angular position to align with the North reference. This North marker appears in the receiver inputs via the antenna switching. Any bearing angle is thereafter determined with respect to the North marker.

The two inputs to the selected dual-path receiver channel are the r-f inputs, in sequence, from the dipole pairs. The two final i-f outputs are fed to the 'phase comparator'. The output of the phase comparator, through 360° of 'rotation', contains bearing angle information with respect to the North marker. (Since there is no real dipole movement, modulation (a-m and f-m) and noise are effectively cancelled).

The 'bearing processor' processes the phase comparator output to obtain the bearing angle in electronic form.

The bearing angle (±0.1°) along with other data (such as control/indication, channel select, frequency select, etc.) is converted to parallel digital form for display purposes. Also, all data exchanged between the antenna/receiver and ATC tower sites is converted to serial data form for transmission along the 4-wire telephone cable in either or both directions.

Other features of the 300 system (not shown in Fig. 3.2.1) include the following;

In Fig. 3.2.2, the r-f and i-f waveforms are shown only as an idealized series of envelopes caused by the dipole pair switching steps. These envelopes are numbered 1 through 16 to correspond with the dipole sampling scan. The actual frequency waveforms within these envelopes must retain their exact phase relationship right to the phase comparison point in the phase comparator.

In the Figure, the switching envelopes are shown divided by a line. This line results from a double switching within the main switching interval. For example, dipoles 3 and 4 are first sampled in clockwise number order 3-4 (first half of interval) and second in counterclockwise number order 4-3 (second half of interval). This double switching occurs for all dipole pairs around the array. Thus, over 360°, there are sixteen main switching intervals containing a total of thirty-two half intervals.

The purpose of the reversed double sampling described above is to 'average out' any minor phase imbalance that might still exist between receiver paths 'A' and 'B'. In effect, there are two simulated dipole pairs that 'rotate' in opposite directions. The switching envelopes of the detected i-f (shown in the phase comparator block) will, as a consequence, have two phases 180° apart. One phase corresponds to a simulated clockwise roating pair, and the other to a simulated counterclockwise rotating pair.

Although the final i-f outputs are limited to equal amplitude, this is only to ensure a reasonably balanced input to the phase comparator. Any modulation (a-m or f-m) including noise is effectively cancelled because the phase comparator is phase sensitive only. This is why, in Fig. 3.2.2, no modulation is shown.

In the phase comparator, the phase comparison point is, for the present purpose, an arbitrary name, which avoids lengthy description. It may be regarded as producing the detected envelope of the i-f frequency with stepped sine function contour as shown idealized in Fig. 3.2.2.

The envelope contour of the phase comparator stepped output waveform is related to the bearing angle of the received signal. It will be observed that an indicated bearing (225°) is shown on a line extended through the mid points of dipole pairs 3-4 and 11-12. Therefore, both dipoles of these particular pairs will pick up the signal with equal phase angle only at the instant that they are scanned on the bearing line. This is indicated by the detected i-f frequency contour nulls shown within the phase comparator block.

- Omni-directional antenna (see below for use)
- Omni-directional receiver for voice transmission pick-up.
- Omni-directional receiver pick-up on 121.5 MHz for optional automatic emergency channel selection in the dual-path receiver.
- Four test antennas mounted on the dipole array and used for preventive maintenance purposes.
- Bearing readout reversible by 180°

3.3 Principle of Operation (Fig. 3.2.2)

3.3.1 DF Bearing

The stationary 16 dipole array is electronically scanned (switched) in pairs of dipoles around the array circle. Assuming the dipoles to be consecutively numbered clockwise (top view) 1 through 16, the scan sequence by pair is 1-2, 2-3, 3-4, ... 15-16. This 360° scan sequence repeats at a rate of about 100 Hz.

The scan sequence simulates the rotation of one pair of dipoles. This simulated pair 'rotates' about its mid-spacing point in angular steps of 22.5° through 360°. In real terms, there is no absolute or relative movement of the dipoles. However, the simulated dipole pair appears to travel around the circle circumference, thus creating a small error of positioning. In practice, this error is negligible.

Since there is no absolute or relative real movement of the antenna dipoles at any instant of time, there is no Doppler effect (frequency change) involved. This is the reason for calling the 300 system a 'Quasi-Doppler' system.

For every angular step position of the 'rotating' dipole pair, a signal is picked up at effectively equal amplitude in both dipoles. These signals will have a difference (or null) in timing which can be measured as a phase angle.

For the purpose of measuring phase angle between dipole pair inputs, the receiver channel must consist of two identical paths 'A' and 'B'. Each of these paths has three i-f conversions including the final i-f. Throughout each path, the design ensures that no spurious i-f phase changes will occur relative to each path. The two final i-f outputs are applied to a 'phase comparator'.

Through 360°, only *one* i-f contour null will represent the bearing angle. This particular null represents the change point in i-f switching *envelope* phase from - to + (i.e. 180°) for dipole pairs scanned in *clockwise number order only*. Thus, *only* the envelope contour of dipole pairs scanned in clockwise number order will contribute to the sine wave derived in the bearing processor.

The phase comparator output is fed into a 'bearing processor' section (shown only by function as an idealized bearing definition waveform in Fig. 3.2.2). In the bearing processor, the stepped sine function waveform is extracted from the i-f contour envelope waveform.

It will be recalled that a North marker was inserted into the receiver input. The leading edge of this marker represents the 0° angle from which the bearing angle can be computed.

The waveform steps are used as samples converted to digital values and fed to a discrete Fourier Transform Processor which operates in reference to the North pulse leading edge. The output of this processor is the fundamental component of the phase signal, corresponding to the bearing angle of the target.

On the operator's control and display panel, the indicated bearing will appear both as a numerical and analog display.

3.3.2 Transmission of Audio and DF Data

The DF information and the output from the audio channel are transmitted to the Local Control/Display Unit by means of a standard 600 Ohm, 4-wire telephone cable. For this purpose, it is necessary to provide a set of 'data above voice' modems. The digital bearing data, and any other bits of information, such as the 'data valid' signal derived from the S/N detector are converted from parallel to series mode and applied to modulate an FSK transmitter, operating in the 2.4 - 3.0 kHz band. The remaining portion of the spectrum (300 - 2300 Hz) is utilized to transmit the audio tone. Some 30 bits of information are envisaged including a parity bit for bearing data, so that the time required for the data to pass need not exceed 0.1 second.

At the Local Control/Display end the audio and data signals are separated and converted back to parallel mode for display at the local bearing indicator. A memory unit is automatically re-charged with the incoming data and retains the readout when the target ceases to transmit, as signalled by the 'data valid' pulse. The operator can disengage the store manually.

A 'system alarm" is provided, indicating a break of transmission from remote to local or a power failure at the remote end. This operates on detecting the presence of the FSK guard carrier from the 'data above voice' modem. A 'remote control' indicator lights up when the system is operated manually from the remote end.

An 'emergency alarm' is transmitted when a signal is present in the emergency channel band (emergency call option).

Another 'data above voice' modem is used to transmit control information to the remote unit and to the antenna head. This includes:

Channel Selection (12 positions)

QDR/QDM Selection

Remote Power ON/OFF

Integration Constant (min. 4 positions)

Antenna Simulator ON/OFF (test facility option)

Emergency Auto-manual (emergency call option)

and min. 6 spare bits

Dual or multiple control/display facilities can be made available.

3.3.3 Synthesized Local Oscillator

The local oscillator in the Receiver Head is of the phase lock loop type. locked to multiples of 25 khz, so that selection of the tuning frequency is obtained by programming the frequency dividing counters. Stability is ensured by deriving the 25 kHz source from a temperature compensated master crystal oscillator. Up to 10 pre-programmed channels are available and the programming is made directly on the circuit board. A limited range AFC facility is provided to lock onto the transmitter frequency and to ensure accurate tuning to the centre of the i.f. in case of transmitter drift.

Selection of any of the 720 frequency channels is also possible by dialing 'frequency mode' and then the frequency in MHz required. In either case (channel or frequency selection) an indication of the selected frequency is returned from the receiver and appears on the operator's panel.

3.3.4 Emergency Channel

In this option, emergency call signals at 121.5 MHz are monitored by the centre antenna and processed via a separate emergency receiver with fixed tuning, terminating in a detector, the output of which responds to the emergency condition.

In accordance with operational requirements, two modes of Emergency Channel are provided.

Mode 1 - Fully Automatic

In the auto position, the detection of an emergency signal automatically allows the Direction Finder to determine a bearing and to transmit bearing data to the local site. In addition. an emergency status signal is transmitted to the local site where it illuminates an emergency indicator and sounds an audible alarm at both local and remote sites. A long release time constant ensures that the alarm remains locked even on pulsed signals. This override function will revert to normal at the end of the emergency call.

Mode 2 -- Manual

In this mode. the MAN-AUTO switch is placed in the MAN position. Upon detection of an emergency signal. an emergency status signal is transmitted to the local site to illuminate the emergency indicator and sound the audible alarm. The operator may then, at his discretion, operate a switch to select the emergency channel frequency.

3.3.5 Built-in Test Facilities

Accuracy and alignment of the DF section can be tested in absence of a transmitting target by means of the antenna simulator synchronized with the commutation frequency. A set of four artificial bearing readouts is generated, selectable from the local control unit. This facility is optional.

Taking advantage of the built-in 'data above voice' modems, a service telephone facility is provided to link the local and the remote sites by using standard 2-wire telephone sets (not provided). The 2-wire/4-wire hybrids are substituted for the audio channel as the telephone set is inserted in the service jack.

3.4 Installation Configuration

A typical installation configuration is shown in Fig. 3.4.3.

Three units and one antenna array (with omni-directional antenna, warning lights, support column, etc.) comprise the basic equipment to be installed (see Section 2).

User-supplied basic equipment includes: AC power lines, antenna mast or tower, small shelter maintenance shack, telephone cable (4-wire, Class C) and a mounting arrangement or facility for the unit located in the airport control tower.

3.5 Equipment Complement

NOTE: Dimensions and weights given hereunder are approximate.

3.5.1 Antenna, 16-Element

This antenna array installation assembly must be mounted on a suitable mast (user supplied).

The dimensional height of the antenna assembly (from mast top) is 8 ft. 5 in. with lightning conductor 10 ft. 10 in. The diameter of the antenna array (16 dipoles) is about 12 ft. 4 in.

The Antenna Unit is one of the three units in a basic 300 system. However, it is considered to be a part of the antenna assembly because it is mounted inside a weather-proof case mounted on the antenna support column.

3.5.2 Receiver Unit

This unit is located close to the antenna array at the remote site. Since the unit is not weather-proof, it is generally installed in a small shack, which also shelters a simple maintenance work bench facility (the shack and work bench is user supplied).

3.5.3 Interconnection Cable Set

This cable set consists of four rf cables an one multi-conductor control/data cable. These cables interconnect the Antenna Unit and Receiver Unit at the remote site.

The cables comprising the Interconnection Cable Set may have a maximum length of approximately 50 metres. However, the specified cut length may differ between different installations.

The Remote/Local link consists of a standard telephone wire quad, preferably in the form of a buried cable. C1 grade characteristics are advisable to avoid losses at the data transmission frequencies. Up to 10 10 Km distance is envisaged which can be extended by the addition of standard telephone repeaters. An alternative Local/Remote link for short distances up to 100 m will consist of a multicore control cable with the omission of the 'data above voice' modems.

3.5.4 Control/Display Unit

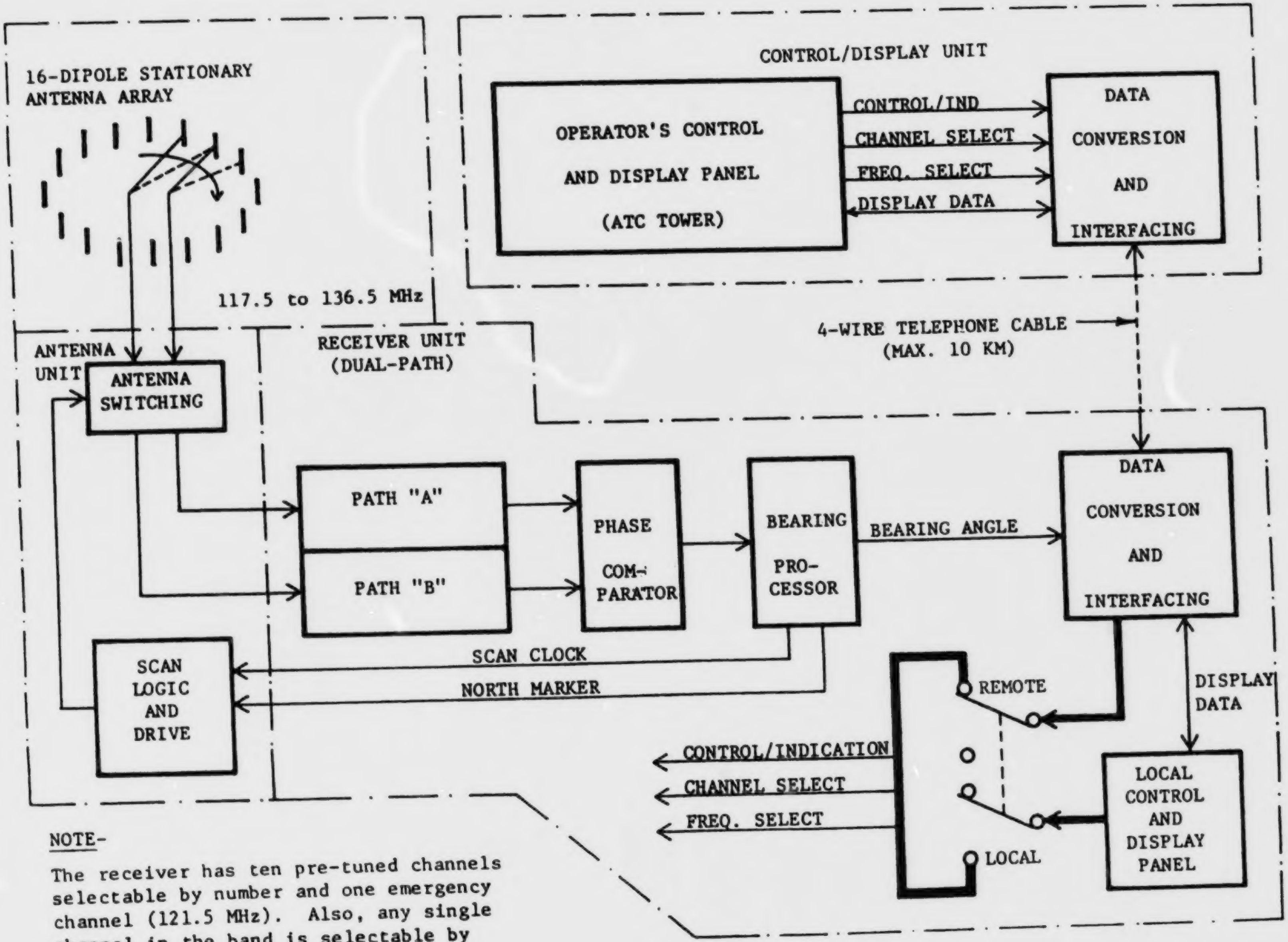
This unit is used by ATC tower operations personnel to control the 300 system. Its preferred installation location is therefore in the airport control tower.

The unit is designed for installation in a standard 19" rack cabinet. If it is required that the unit stand alone (on a desk or table), an optional enclosure box of impact resistant plastic can be supplied.

A particular system installation may be augmented by installing more than one Control/Display Unit. In this case, a front panel switch (on each unit) can be set for 'master' or 'slave' operation. At any given time, only one unit can operate as the 'master'.

Excluding the enclosure box, the unit clearance dimensions in inches/centimetres are:

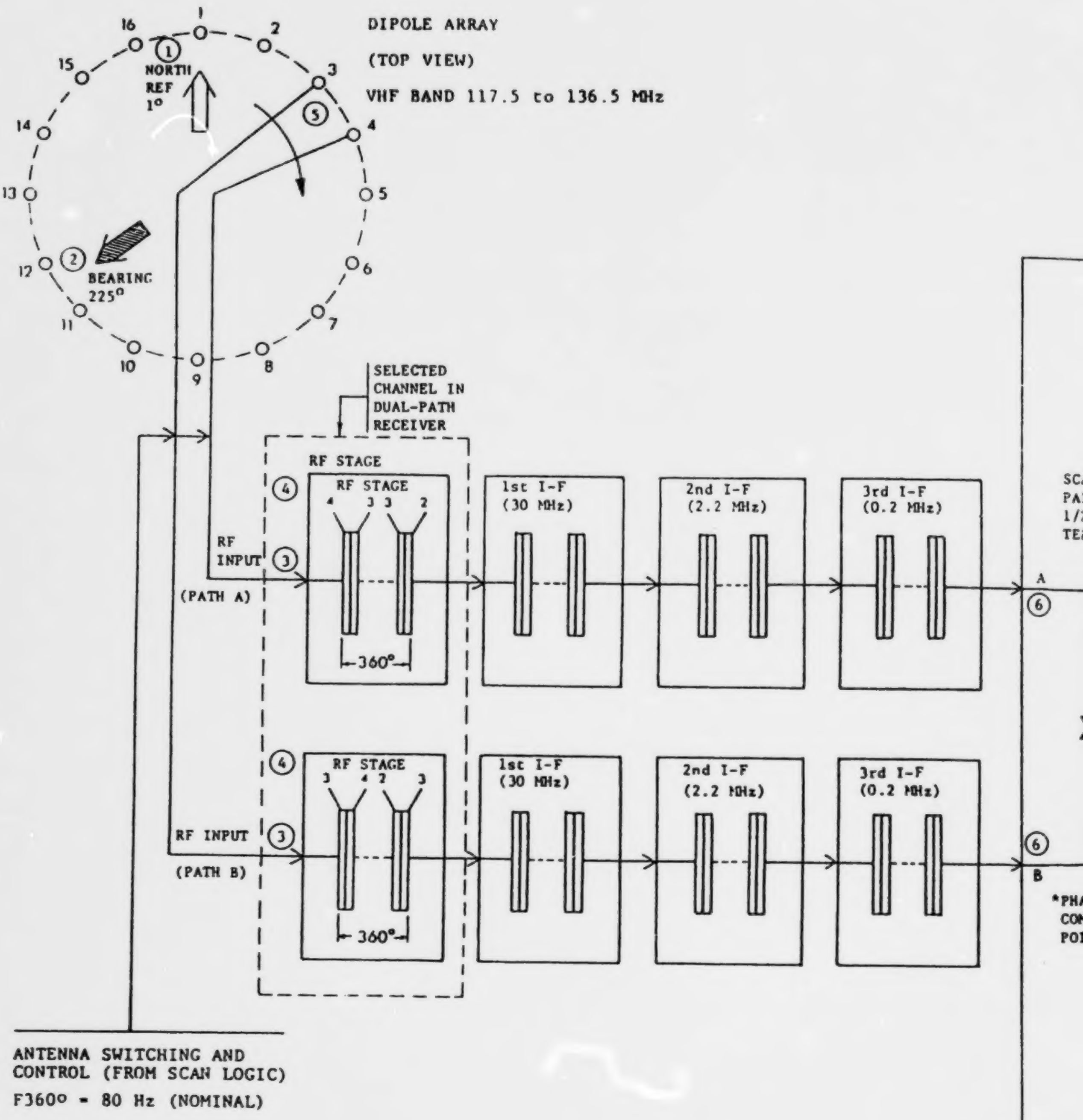
Height:	5.25 in	(21 cm)
Width:	19 in	(47.5 cm)
Depth:	10 in	(25 cm)


16-DIPOLE STATIONARY ANTENNA ARRAY
117.5 to 136.5 MHz
ANTENNA UNIT
ANTENNA SWITCHING
SCAN LOGIC AND DRIVE
RECEIVER UNIT (DUAL-PATH)
PATH "A"
PATH "B"
PHASE COM-PARATOR
BEARING PRO-CESSOR
SCAN CLOCK
NORTH MARKER
BEARING ANGLE
CONTROL/DISPLAY UNIT
OPERATOR'S CONTROL AND DISPLAY PANEL (ATC TOWER)
CONTROL/IND
CHANNEL SELECT
FREQ. SELECT
DISPLAY DATA
DATA CONVERSION AND INTERFACING
4-WIRE TELEPHONE CABLE (MAX. 10 KM)
DATA CONVERSION AND INTERFACING
DISPLAY DATA
LOCAL CONTROL AND DISPLAY PANEL
REMOTE
LOCAL
CONTROL/INDICATION
CHANNEL SELECT
FREQ. SELECT

NOTE-

The receiver has ten pre-tuned channels selectable by number and one emergency channel (121.5 MHz). Also, any single channel in the band is selectable by frequency.

FIGURE 3.2.1 SIMPLIFIED SYSTEM OUTLINE


DIPOLE ARRAY
(TOP VIEW)
VHF BAND 117.5 to 136.5 MHz
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
①
NORTH REF 1°
⑤
②
BEARING 225°
SELECTED CHANNEL IN DUAL-PATH RECEIVER
RF STAGE
④
RF STAGE
4 3 3 2
RF INPUT ③
(PATH A)
360°
1st I-F (30 MHz)
2nd I-F (2.2 MHz)
3rd I-F (0.2 MHz)
A
⑥
SC
PA
1/
TE
④
RF STAGE
3 4 2 3
RF INPUT ③
(PATH B)
360°
1st I-F (30 MHz)
2nd I-F (2.2 MHz)
3rd I-F (0.2 MHz)
⑥
B
*PH
CO
PO
ANTENNA SWITCHING AND CONTROL (FROM SCAN LOGIC)
F360° = 80 Hz (NOMINAL)

NOTES:

① North reference marker appears in receiver output.

② Indicated bearing is at 90° to dipole pairs 3-4 and 11-12.

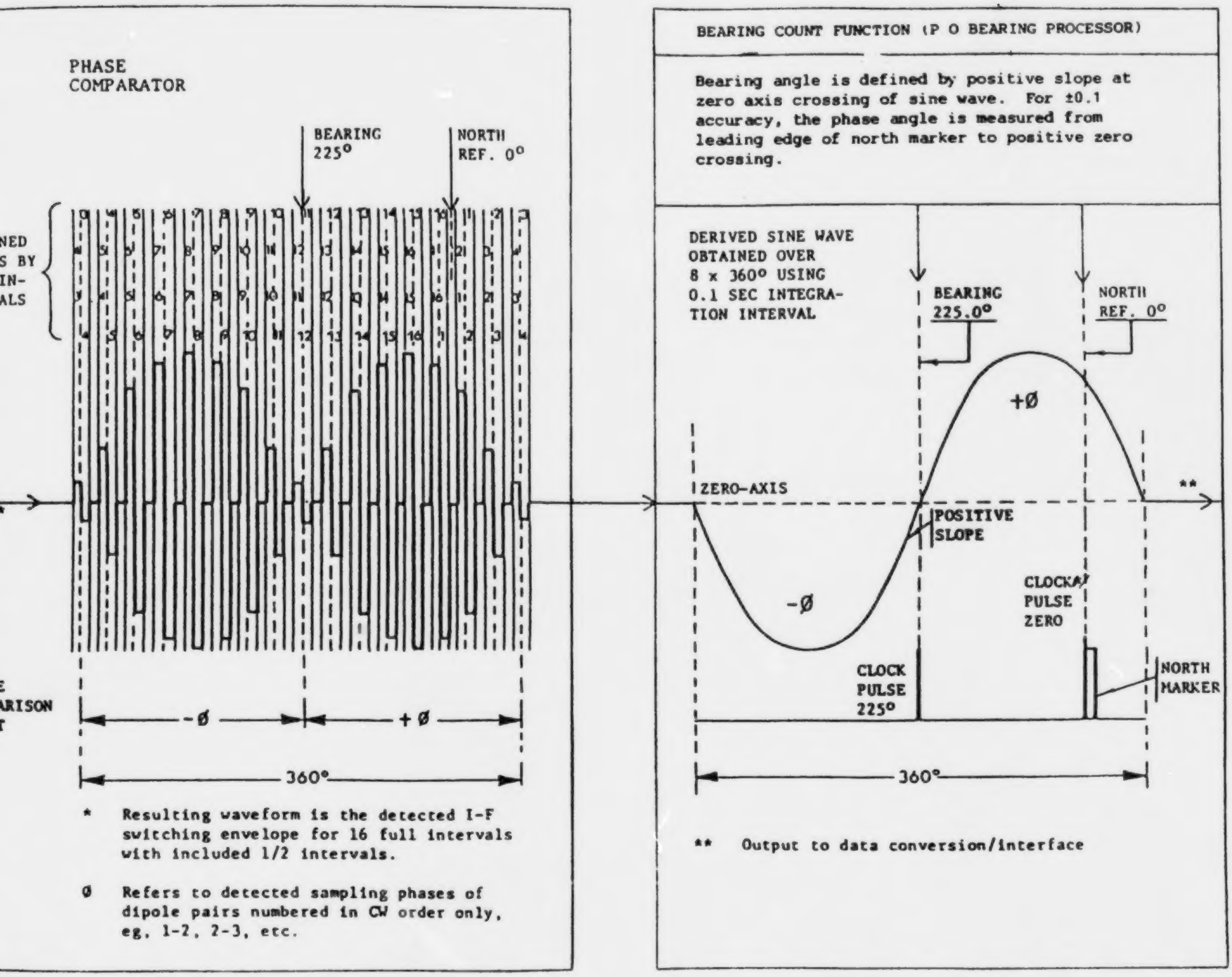
③ Frequency waveforms are shown as sampling (switching) envelope intervals only. The --- lines indicate total of 16 full intervals over 360°. Full intervals are split into 1/2 intervals.

④ Numbers identify dipoles and associated sampling envelopes.

⑤ During every switching interval, the dipole pair output is sampled twice; eg, in the two 1/2 intervals, dipole connections are: first 3-4, second 4-3.

⑥ Phase comparison is made between paths 'A' and 'B' for equal-timed 1/2 intervals.

⑦ Signal modulation cancels out (not shown).



PHASE COMPARATOR
BEARING 225°
NORTH REF. 0°
NED
S BY
IN-
ALS
E
ARISON
T
-Ø
+Ø
360°
BEARING COUNT FUNCTION (P O BEARING PROCESSOR)
DERIVED SINE WAVE OBTAINED OVER 8 x 360° USING 0.1 SEC INTEGRATION INTERVAL
BEARING 225.0°
NORTH REF. 0°
+Ø
ZERO-AXIS
**
POSITIVE SLOPE
-Ø
CLOCK PULSE ZERO
CLOCK PULSE 225°
NORTH MARKER
360°

Bearing angle is defined by positive slope at zero axis crossing of sine wave. For ±0.1 accuracy, the phase angle is measured from leading edge of north marker to positive zero crossing.

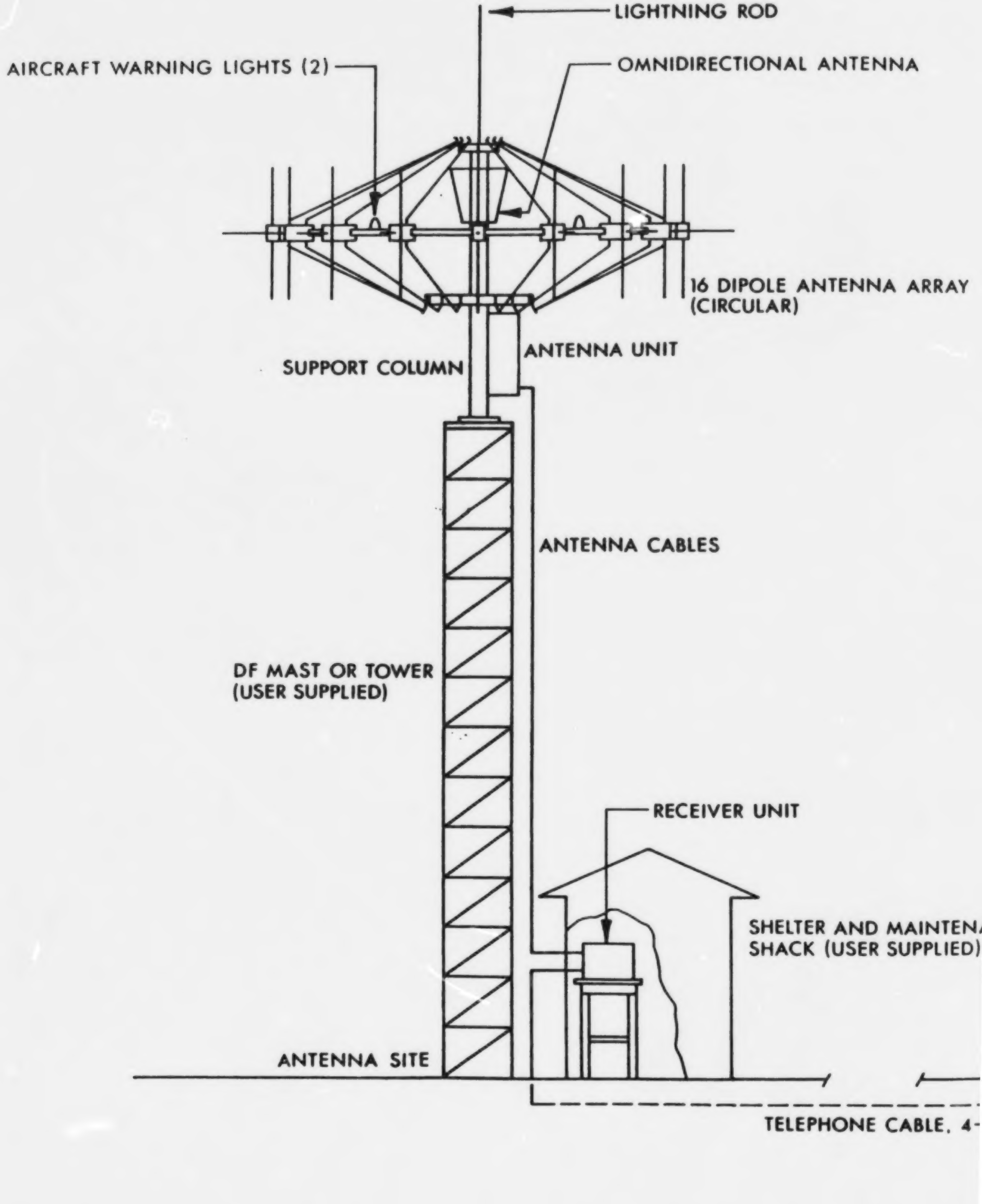
* Resulting waveform is the detected I-F switching envelope for 16 full intervals with included 1/2 intervals.

Ø Refers to detected sampling phases of dipole pairs numbered in CW order only, eg. 1-2, 2-3, etc.

** Output to data conversion/interface

FIGURE 3.2.2

PRINCIPLE OF OPERATION


LIGHTNING ROD
AIRCRAFT WARNING LIGHTS (2)
OMNIDIRECTIONAL ANTENNA
16 DIPOLE ANTENNA ARRAY (CIRCULAR)
ANTENNA UNIT
SUPPORT COLUMN
ANTENNA CABLES
DF MAST OR TOWER (USER SUPPLIED)
RECEIVER UNIT
SHELTER AND MAINTEN
SHACK (USER SUPPLIED)
ANTENNA SITE
TELEPHONE CABLE, 4-

NOTES:

1. MAXIMUM LENGTH OF ANTENNA CABLES IS 50M.
2. TELEPHONE CABLE LENGTH MUST NOT EXCEED 10KM.

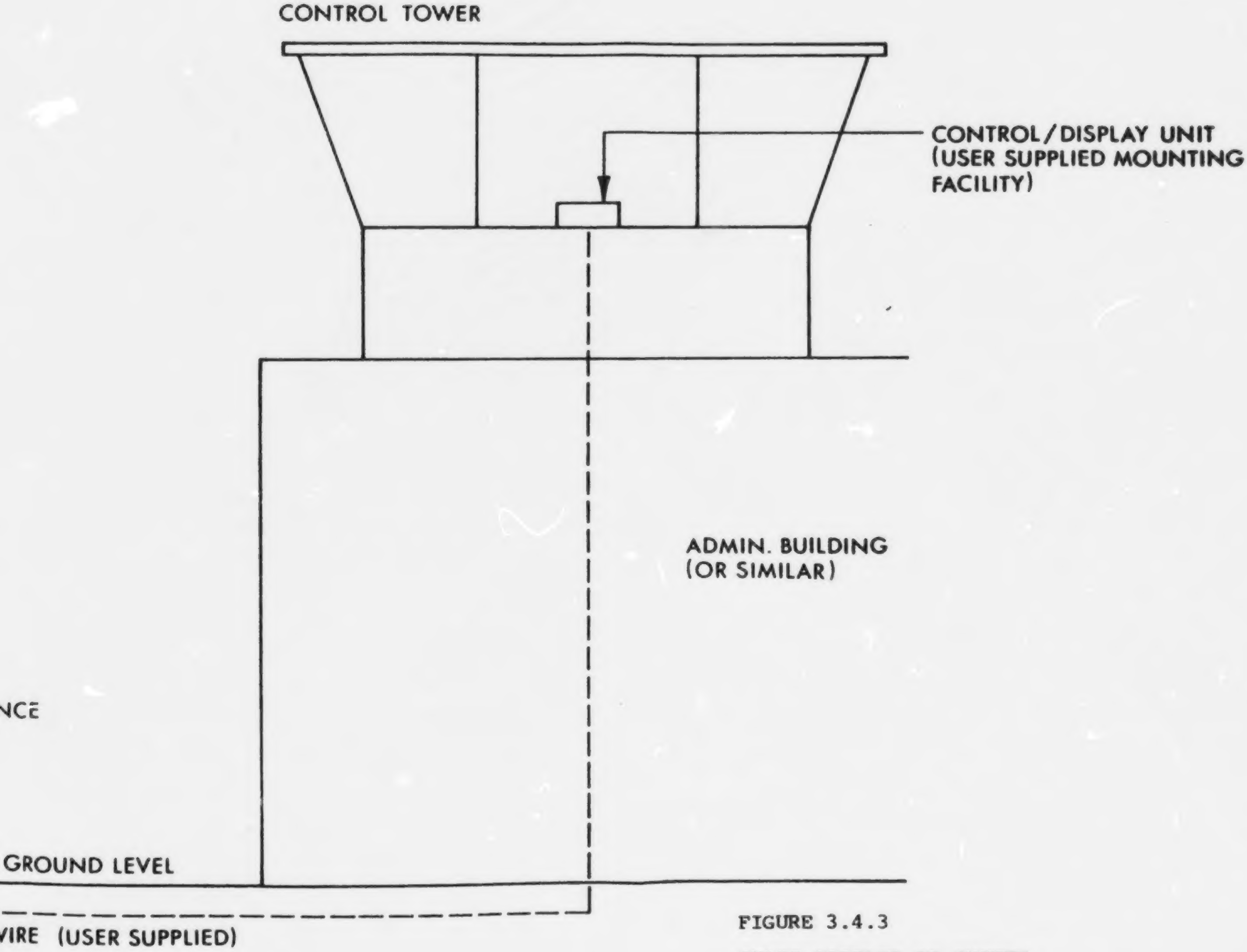

CONTROL TOWER
CONTROL/DISPLAY UNIT (USER SUPPLIED MOUNTING FACILITY)
ADMIN. BUILDING (OR SIMILAR)
NCE
GROUND LEVEL
VIRE (USER SUPPLIED)

FIGURE 3.4.3

QUASI-DOPPLER DF SYSTEM
TYPICAL INSTALLATION CONFIGURATION

4. SPECIFICATIONS (PRELIMINARY)

QUASI-DOPPLER DF SYSTEM 300

4.1 DF System

Frequency Range	117.5-136.5 MHz (civilian air traffic control) VHF
Principle of Operation	Large aperture Quasi-Doppler with differential sampling
System Accuracy	≤1.5° with 16 elements
RF Noise Figure	≤7 dB
Polarization Error	Approx. 1° with 45° tilt
Sensitivity (vertical polarization)	≤3 V/m for ±1° accuracy
Antenna immunity to reflections as compared with Adcock DF	Min. 6 times improvement with 16 elements
Group Delay Error	Cancelled out by digital processing
Antenna Scanning Frequency	Adjustable to clear interference flicker
DF Receiver Phase Match Error	Cancelled out by channel commutation
Mode Operation	Continuous, unattended
Number of Frequency Channels	Emergency channel plus 10 switch selected - each channel frequency programmable within the equipment; full range of 720 channels, operator selectable, available as option.
Channel Spacing	25 kHz
Acceptance Bandwidth	Approx. ±50 ppm of the carrier frequency.

Adjacent Channel Breakthrough : ≤1° error with adjacent channel signal up to 50 dB above wanted signal but not exceeding 3 mV/m

Bearing Indication : 4 digits with LED display numerals blanking out at no signal unless connected to store; display at both local and remote units.

Sense Indication : QDR or QDM selectable from control panel and indicated below the bearing data

Response Time : 100 ms to 0.8 sec., depending on the signal strength and the setting of integration constant

Bearing Readout Update : Equal to integration constant

Valid Display Indicator : On the local control unit

Local Panel Controls : Power ON/OFF; dimmer (bearing and channel display only); lamp test; channel select (illum. pushbutton); QDM/QDR; integration (3 positions); store ON/OFF with indicator; remote control indicator; system alarm indicator; signal overhead indicator; scan frequency

Remote Panel Controls : Power ON/OFF; local/remote switch and indicator; squelch ON/OFF; channel frequency indicator and manual override channel selector; channel balance

Auxiliary Data Output : At both local and remote units, TTL compatible parallel data bit format

Auxiliary Channel Select : At the remote unit for control from another site

Squelch Threshold : Fully adjustable from front panel of remote

Service Telephone : Jacks provided for 2-way communications between remote and local units (audio channel disabled)

Aircraft Warning Light : Integrated with antenna structure (may be left out if not required)

Cables

Antenna Head to Remote Receiver : 2 coaxial double-shielded ¼" and 1 multicore; 50 m max; RF connectors (N-type)

Remote to Local Short Distance Option : 4 wire telephone line - 10 Km max. multicore cable 100 m max.

Multiple Control Stations Option : Two or more local panel controls can be interconnected by switching at the 4-wire telephone line level

4.2 Audio Monitoring Option

Monitor Antenna : Centre of the array

Frequency : Automatically tuned with the DF system

Receiver Sensitivity : 7 dB NF

Type of Detector : AM or FM selectable on the Remote Unit

Option : Either AM or FM as requested

Output : 0.5 W loudspeakers on both remote and local units, provided with on/off switches

Auxiliary Output : 50 mW at 600 ohms on the Local Unit

Squelch : Provided on the Remote Unit

AGC : Provided on the Remote Unit

Volume Control : Individual with each loudspeaker

Additional Cable

Antenna Head to Remote Receiver : Coaxial, double-shielded ¼ inch, 50 m max (N-type connectors)

4.3 Emergency Call Option

Antenna : Common with audio monitoring provided with separator filter

Receiver Sensitivity : 7 dB NF

Tuning : Set at 121.5 MHz or as required within +0% - 30% of the top frequency of the RF range

AGC : Pre-set

Detector : Carrier presence above threshold pre-set at the Remote Unit

Additional Controls

Auto/Man : At both Local and Remote Units

Alarm : LED indicators at Local and Remote Units

Additional Cable

Antenna Head to Remote Receiver : Coaxial, double-shielded, ¼ inch 50 m max (N-type connectors)

4.4 Antenna Simulator Test Injection Option

Antenna Test Injection : Provides selection of 4 simulated targets at 45°, 135°, 225°, and 315° locations

RF Test Source : Generates a synthetic rf signal by adding i-f to the LO frequency

Location : In the Antenna head

Control : Pushbutton from Local Unit (Note: Normal operation is disengaged when operating the antenna simulator)

4.5 Environmental

Temperature Range Operational

Antenna : -55°C to +55°C

Local and Remote Unit ; -20°C to +55°C

Humidity : 95% max.

Wind Load (Antenna) : 160 Km/hr max.

Salt Spray (Antenna) : Equivalent to MIL specifications

Drip-proofing (Antenna) : Equivalent to MIL specifications

Ice Formation (Antenna) : Up to 2 inch thickness

5. ANTENNA SUB-SYSTEM

5.1 Antenna Design Approach

The Doppler antenna array was developed under the following assumptions based on established engineering practice:

- The array was limited to 16 dipoles for the accuracy required. The dipoles were mounted with a precision corresponding to better than 0.01° of the bearing angle.
- Spacing between the dipoles was selected at 120° max. of the highest signal frequency, so as to give the highest possible sensitivity with adequate margin of phase waveform distortion.
- The dipoles were mounted at the outer points of a star-shaped ground plane made up of a mesh, stainless steel, tension cable.
- Horizontal counterpoises were provided outside the dipole circle in order to improve balance of the polar patterns and immunity to pick up of horizontally polarized waves.
- All dipoles were connected to the switching network with a set of coaxial matched cables of equal phase length.
- The dipole design incorporated a unique lightning protection feature - a short circuiting centre rod of a length corresponding to ½ wavelength for the band of frequencies in use. This rod is bonded at the centre to the ground plane of the array.
- Additional Corona protection was provided by placing neon lamps across each dipole element.
- The omni-directional antenna for audio and emergency channels was placed around the centre mast near the ground plane with an alternative position for mounting it in an elevated position above the dipole array. A decision as to which position to use was left to the results of field trials.

5.2 Measurements of Dipole Impedance and Interaction

In order to test the antenna design, three prototype dipoles were constructed and tested on a simulated section of ground plane. The dipoles were constructed of 1.5" diameter aluminum tubing. This length was 45" from tip to tip. Ground rods were simulated with lengths of 0.375" diameter aluminum tubing.

The ground plan was constructed on a wooden platform. The dipoles were mounted on the actual support plates that will be used on the final antenna. Aluminum wires were fastened to these plates in the same orientation as in the antenna. The ground rods were also fastened to the support plates.

The actual measurements were made with a Hewlett Packard 8754A network analyzer and 8502A transmission reflection test set. With this equipment the impedance is displayed directly on a Smith chart. These impedance measurements are referenced to the gap of the antenna in each case. The normalizing impedance is 50 Ohm.

Figure 5.2.1 shows the impedance of a single dipole in free space. When this dipole is mounted on the ground phase the impedance grouping spreads out as shown in Figure 5.2.2.

Figure 5.2.3 shows the effect of adding a dipole on each side of the measured dipole. These 2 dipoles were terminated in 75 Ohms. Transforming this impedance to 75 Ohms shows that the best impedance match is from 110 MHz to 130 MHz. This will give a maximum VSWR of 2:1. In order to adjust the frequency of the dipoles to the required band, the dipoles must be shortened by a factor of 0.94.

The effect of removing the ground rods is negligible as shown by Fig. 5.2.4.

Figures 5.2.5 and 5.2.6 show the impedance of the centre antenna when the outer antennas are short circuited and open circuited respectively. The largest amount of interaction occurs with the short circuit terminations. These impedance plots show the importance of terminating the unused dipoles in 75 Ohms.

These tests show that the dipoles are performing as expected. One important aspect of them is that there is no special impedance matching required. This will mean that the phase matching involves the tolerance on the physical length of the dipole and the electrical length of the feed cable. It will thus be possible to produce dipoles with closely matched phase responses.

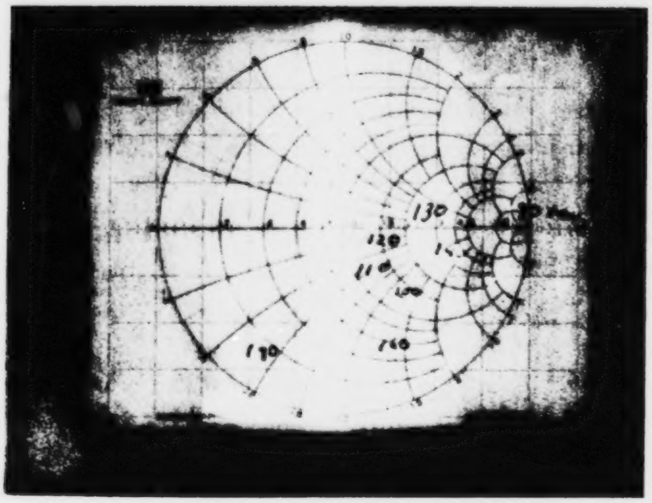


FIGURE 5.2.1

DIPOLE IMPEDANCE -
FREE SPACE

FIGURE 5.2.2

DIPOLE IMPEDANCE ON
GROUND PLANE

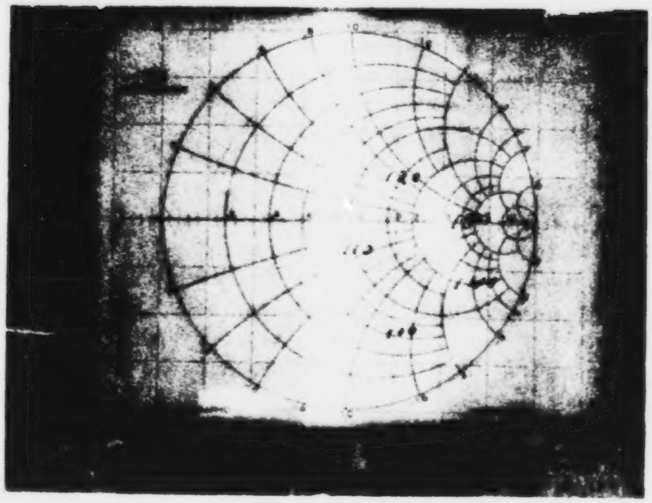


FIGURE 5.2.3

EFFECT OF ADJACENT DIPOLES
WHEN TERMINATED INTO 75 OHMS

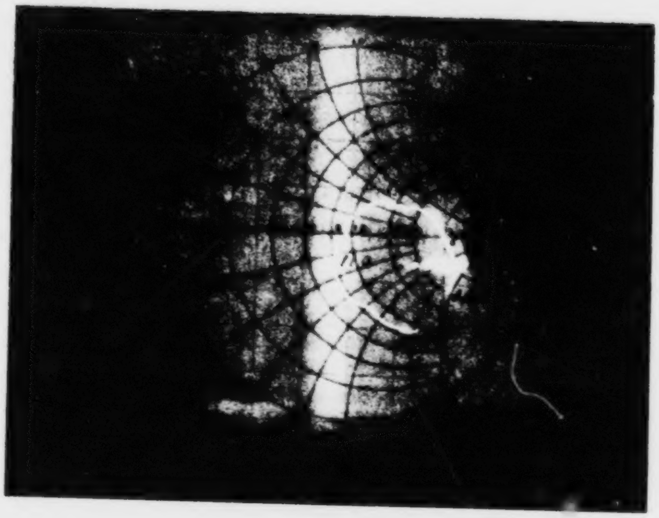


FIGURE 5.2.4

EFFECT OF REMOVING GROUND RODS

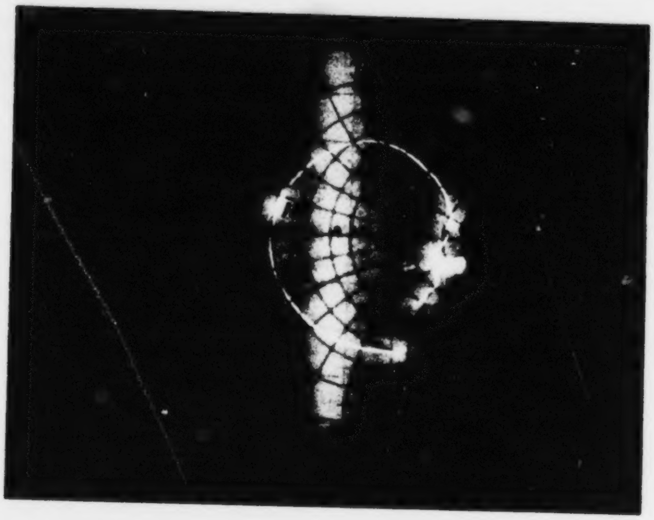


FIGURE 5.2.5

TERMINATION OF ADJACENT DIPOLES BY SHORT CIRCUIT

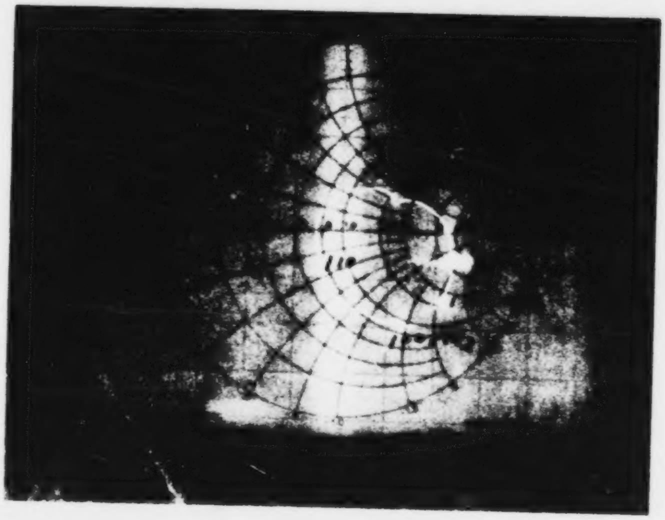


FIGURE 5.2.6

TERMINATION OF ADJACENT DIPOLES BY OPEN CIRCUIT

5.3 Soft Switching Technique for Reduction of Adjacent Channel Interference

Thsi report describes the work conducted to determine the influence of the waveform used for driving the antenna commutator switch on the overall intermodulation (IM) products generated on the outputs of the switch.

As stated in previous reports, early Doppler directional finders used a physically rotating antenna pair producing a signal which has modulated at the rate of rotation of the antenna. However, in later developments, antenna rotation was replaced by sequential switching of a series of fixed dipoles arranged in circular array. The outcome of this sequential sampling produces from each dipole an RF signal which is interrupted at the rate of the scanning frequency, i.e. a pulse modulated signal. This signal, therefore, is made up of the fundamental RF frequency, in addition to the upper and lower sidebands of all the components of the switching frequency. These additional products can extend over a bandwidth covering several hundred kHz (Fig. 5.3.1) creating interference on a large number of adjacent channels and resulting in severe degradation in DF performance. From this, it follows that, if the switching action is accomplished closer to a sinusoidal pattern 'Soft Switch', fewer of the higher order products will be generated.

While it is extremely difficult to achieve such a function using a mechanical switch, it is nevertheless possible to build a switch whose transfer functions is controlled by the shape of the driver output waveform by using PIN diodes as the switching elements. The PIN diode could be considered as a variable RF resistor whose resistance is inversely proportional to its current. By employing these diodes in a (T) configuration, it is possible to construct an RF switching having an attenuation which is directly controlled by the shape of the driver waveform (Fig. 5.3.2).

In order to investigate the effects of Soft Switching on the overall intermodulation products, a similar switch to that shown in Figure 5.3.2 was built. It had an insertion loss of 1.2 dB in the 'ON' position and an isolation of 65 dB in 'OFF'. As a reference, a square wave having a peak to peak amplitude of 20 volts was applied to the driver inputs. The RF output is shown in Figure 5.3.3. It can be clearly seen that the IM products are only 42 dB down at ±50 kHz away from carrier. By applying a sinewave to the control inputs, the spectrum analyzer display shown in Figure 5.3.4 clearly demonstrates the suppression of higher order products. The sidebands are now attenuated to 60 dB at ±20 kHz from the carrier.

At ±50 kHz, all products are lower than the internal noise level of the measuring instrument which is 70 dB down from the reference. This test verifies the advantage to be gained in using a soft switching mechanism.

By examining the attenuation versus current response of the switch (Fig. 5.3.5), it can be deduced that the largest change in attenuation occurs during the first few milliamperes of current through the diodes. This implies that the first volt of bias will have the greatest impact on the performance of the switch.

Therefore, it follows that in order to reduce the generation of unwanted IM products, the slope of the input drive voltage must be kept as low as possible. Ideally, a sine square pulse would produce the best result. This was verified by applying a sinewave in combination with a DC bias voltage. The bias was adjusted to ensure the trough of the waveform was just at the point of forward conduction for the series diodes This provides zero slope at the beginning of the conduction cycle. The spectrum was examined and found to be even better than that obtained with the sinewave alone. However, this type of voltage cannot be used to drive the switch in the final product since it does not provide negative bias during the turn off portion of the cycle. Therefore, a waveform, as shown in Fig. 5.3.6 was used. This waveform was generated by driving a sinusoidal signal through a network consisting of diodes and resistors. The slope at the diode's knee is used to provide soft switching for both the on and off conditions, with minimum slope occurring at the transition region. The RF switch was then driven with this signal and the output spectrum is shown in Fig. 5.3.7. As can be seen, the IM products are improved by a further 15 dB as compared to the sinewave drive.

As a result of the soft switching, the RF conduction angle is reduced by the amount of the transition period. With the circuit used, it was possible to secure an 80% duty cycle for the RF signal. The resulting loss of DF sensitivity is negligible.

Conclusion

From the above results, it is concluded that if a soft switch is employed for the commutator switch, the intermodulation products could be reduced by approximately 35 dB as compared to the abrupt change switch at ±10 kHz away from the carrier.

It is also shown that the slope of the transition is most critical during the first few degrees of conduction. The shape of the centre portion of the driving pulse is far less important.

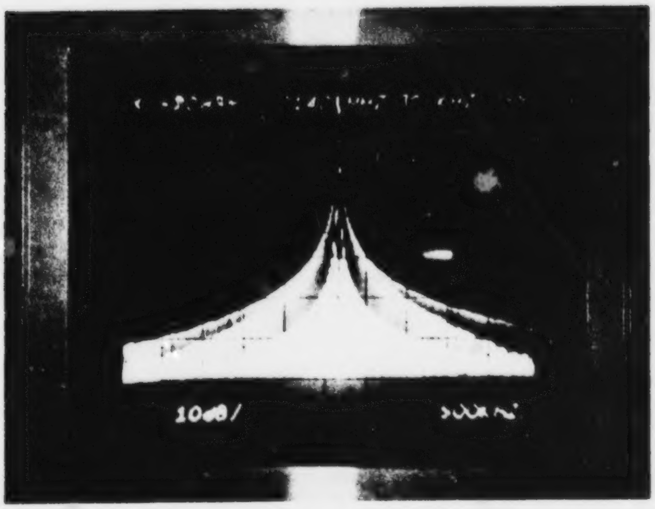


FIG. 5.3.1

OUTPUT SPECTRUM WITH SQUARE WAVE SWITCHING
VERTICAL 10 dB/DIV
HORIZONTAL 500 kHz/DIV

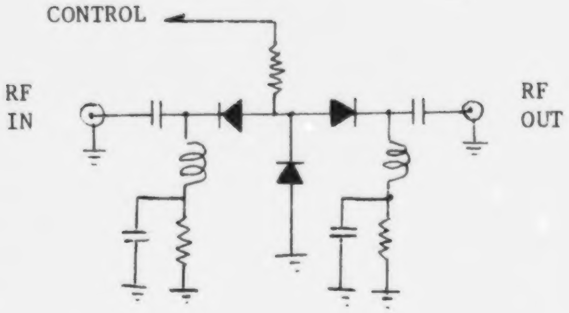

CONTROL
RF
IN
RF
OUT

FIG. 5.3.2

RF SWITCH

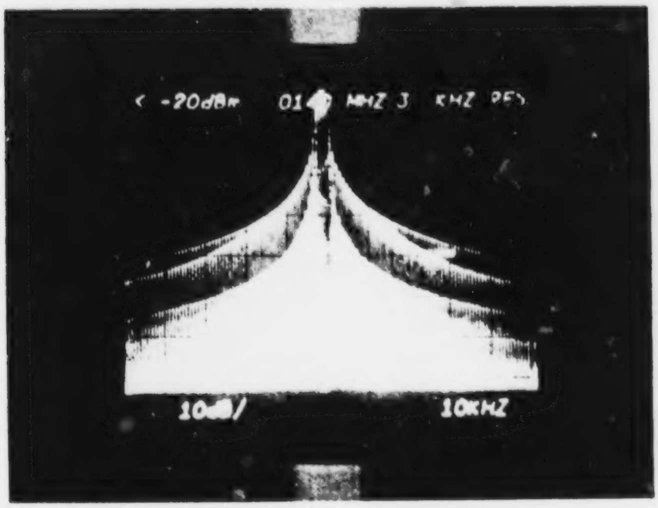


FIG. 5.3.3

OUTPUT SPECTRUM WITH SQUARE WAVE SWITCHING
VERTICAL 10 dB/DIV
HORIZONTAL 10 kHz / DIV

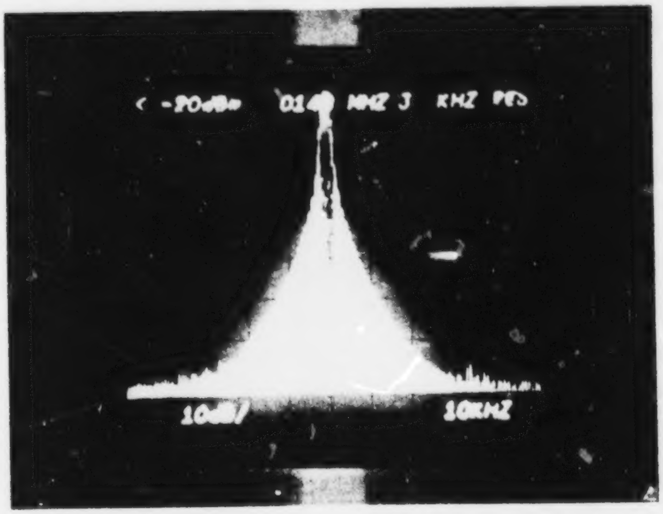


FIG. 5.3.4

OUTPUT SPECTRUM WITH SINUSOIDAL SWITCHING
VERTICAL 10 dB/DIV
HORIZONTAL 10 kHz / DIV

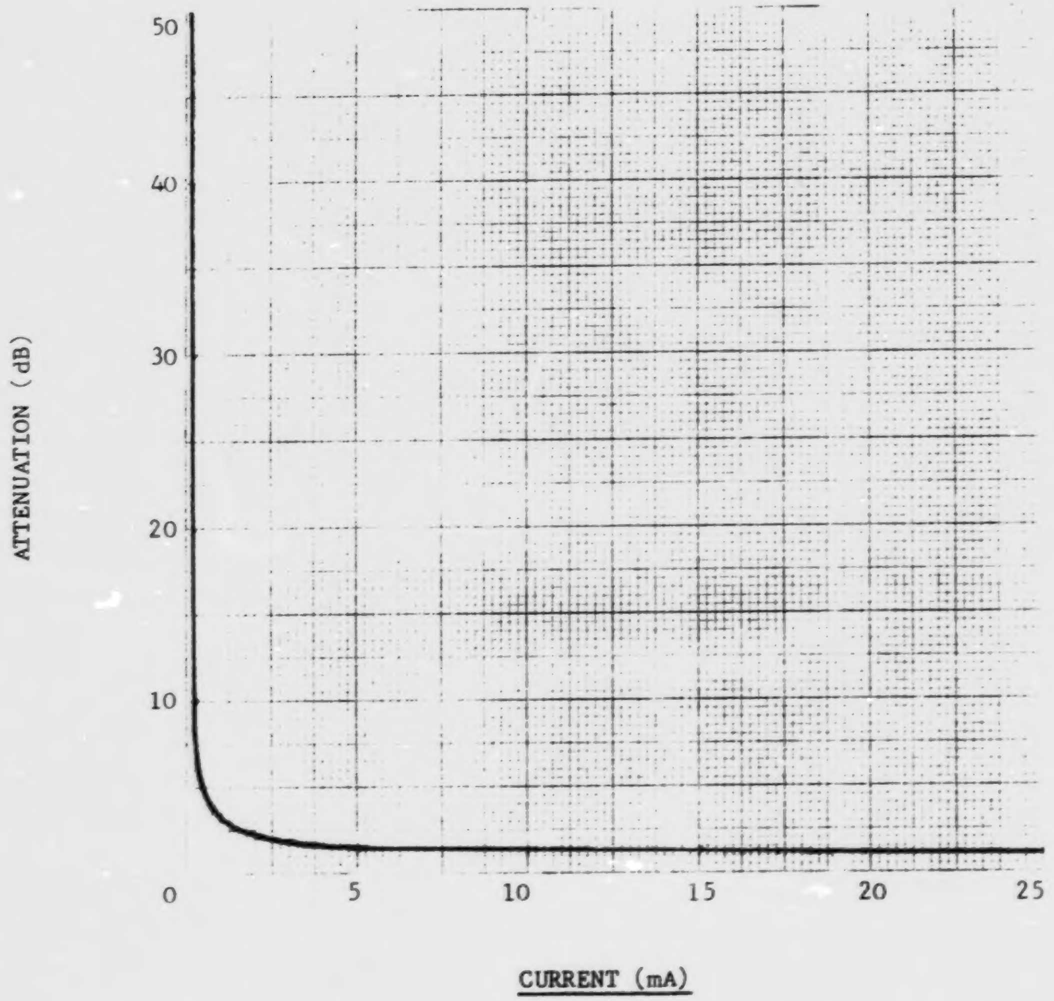


FIG. 5.3.5
ATTENUATION/CURRENT RESPONSE FOR RF SWITCH

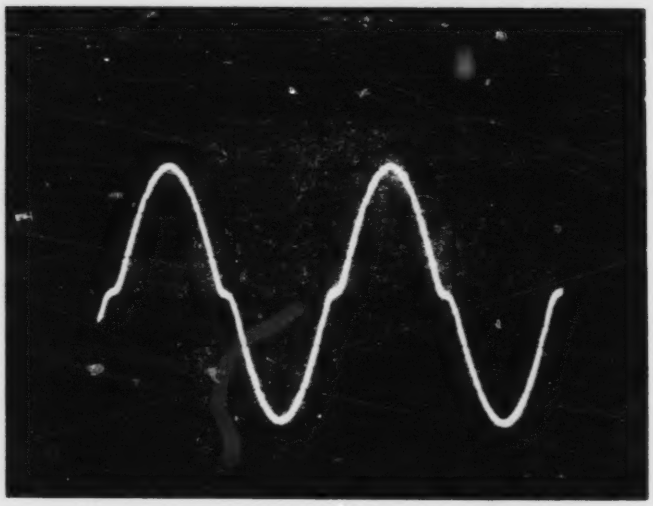


FIG. 5.3.6

PRE-DISTORTED SOFT SWITCH WAVEFORM

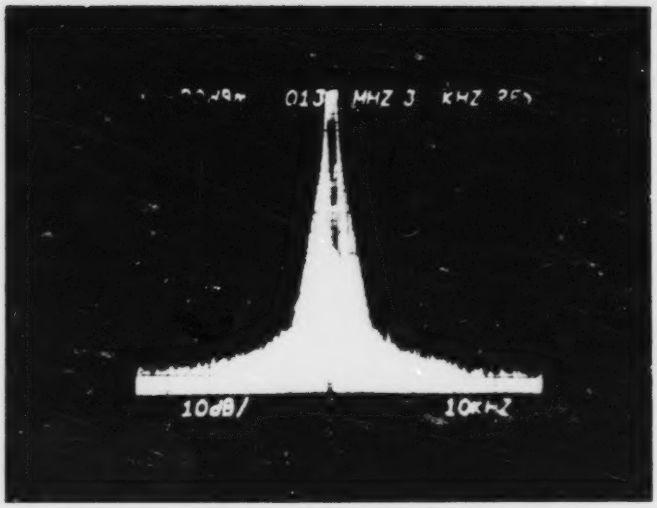


FIG. 5.3.7

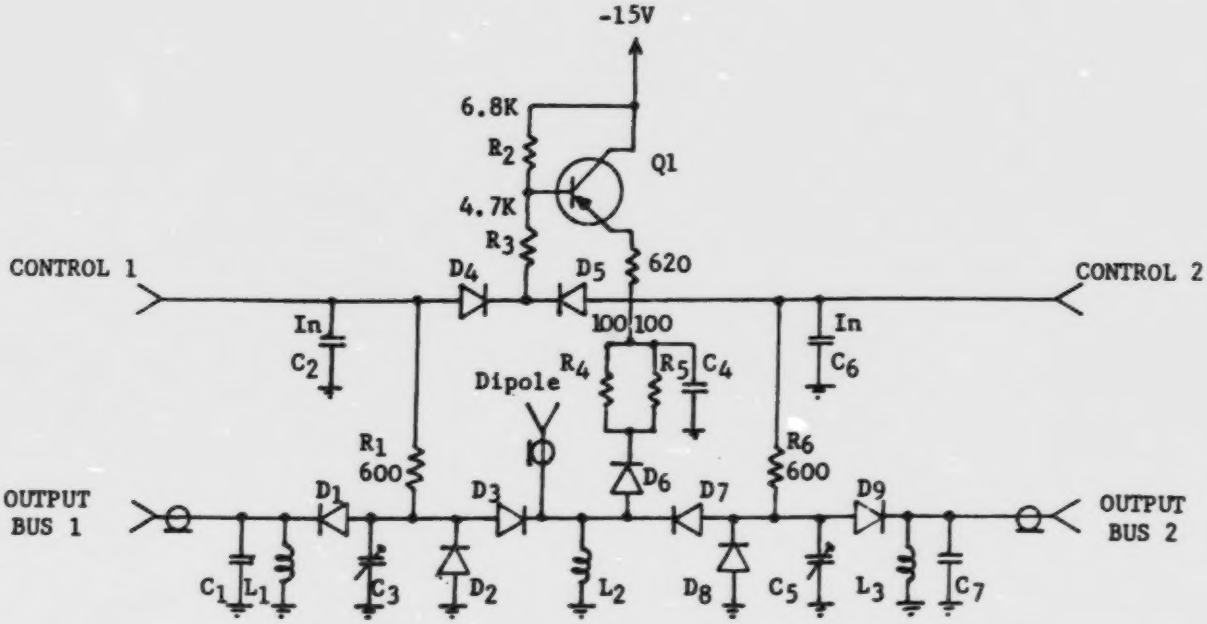
OUTPUT SPECTRUM WITH PRE-DISTORTED WAVEFORM
VERTICAL 10 dB/DIV
HORIZONTAL 10 kHz/DIV

5.4 Unit Dipole Switch - Circuit Diagram

Configuration Used for Performance Testing

The circuit is an equivalent of a 3-way selector, connecting the dipole to Bus 1, Bus 2 or to the Dummy Load (50 Ohms). Controls 2 and 2 are operated independently between +15 V and -15 V in accordance with the following truth table:

Dipole to:	Control 1	Control 2
Bus 1	+	-
Bus 2	-	+
Dummy Load	-	-


-15V
6.8K
R2
Q1
4.7K
R3
620
CONTROL 1
D4
D5
CONTROL 2
In
C2
100
100
R4
R5
C4
In
C6
Dipole
R1
600
D6
R6
600
OUTPUT BUS 1
D1
D3
D7
D9
OUTPUT BUS 2
C1
L1
C3
D2
L2
D8
C5
L3
C7

Diodes D_1 - D_4 and D_7 - D_9 : MA47123
Diodes D_4 and D_5 : 1N914
Transistor Q_1 : 1N2907A

FIG. 5.4.1

UNIT DIPOLE SWITCH - CIRCUIT DIAGRAM

5.5 Mechanical Construction of the Antenna Array

Especially careful consideration was given to the mechanical design of the antenna array. The reason for the considerable attention was two-fold:

1. Design a mechanical structure with an electrically optimized profile to minimize the influence of the structure relative to the accuracy of the DF system.
2. Design a cost effective rigid structure to ensure that no additional errors are introduced to the DF system due to flexing of the structure under varying wind and ice loading conditions.

Under separate contract, three types of structures were analyzed:

1. the traditional cantilever array
2. a fibreglass reinforced support structure, and
3. a modified 'bicycle' wheel structure

After careful analysis of factors such as cost effectiveness, rigidity, manufacturing processes and ease of field installation, the modified bicycle wheel structure was chosen. This type of structure offers inherent rigidity and high torsional stability under all conceivable wind and ice loading conditions.

The environmental conditions specified in the contract were:

160 Km/hr wind load

1 in. of radial ice

In order for Bayly to be compliant with international contract specifications for DF systems (i.e. U.K.) the environmental design specification was upgraded to:

200 Km/hr wind load

2 in. of radial ice

The final design can be described as follows:

A non-metallic ring is suspended from a control mast by virtue of a number of non-metallic rods above and below the centre line of the ring. An array of metallic cables in the centre line of the ring places the ring in tension and, at the same time, provides the necessary ground plane for the antenna.

Precision springs on one end of all rods and cables ensure correct pre-tensioning of all structural members during installation, without the need for any complex tension-measuring devices. The weight of the final antenna array, including dipoles and antenna switching electronics compartment, turned out to be 255 Kg (561 lb.) (dry dead weight).

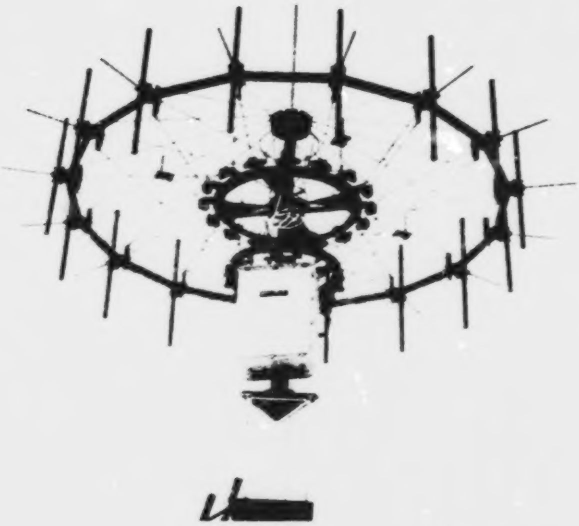


FIG. 5.5.1
PICTORIAL VIEW OF ANTENNA ASSEMBLY

It is Bayly's opinion that a weight saving of approximately 20% can be achieved for future production orders by application of careful weight analysis and minor design changes.

After completion of the final structural analysis and the detail design phase, a prototype antenna array was fabricated at our manufacturing facilities in Granby, Quebec. Prior to field testing of the DF system at the test range, the prototype antenna was assembled in-plant. No faults in the mechanical structure were detectable and, subsequently, the antenna was assembled and tested on the range. During the assembly, it became apparent that the design goal of ease of installation was fully met. A team of two technicians assembled the structure in one and one half days, without the need for any special tools or fixtures, due mainly to the self aligning design of the basic structure.

The following data describes various load conditions at the tower interface flange:

1. Antenna in 200 Km/hr wind, dry condition (no ice):

1.1 Total Weight : 255 Kg.

1.2 Horizontal Windload (shear) : 309 Kg.

1.3 Overturning Moment : 3073.5 ft. lbs

2. Antenna in 100 Km/hr wind, with 2 inches of radial ice:

2.1 Dry weight plus ice load : 2219 Kg.

2.2 Horizontal Windload (shear) : 391 Kg.

2.3 Overturning Moment : 4848.3 ft. lbs

5.6 Polar Patterns Obtained with Antenna Array

Upon completion of its assembly, the Doppler antenna array was first tested for the operation of the individual dipoles and for impedance and phase matching of the coaxial connecting cables. This work was performed in the Company's Granby antenna laboratories. A typical graph of VSWR versus frequency, measured as mounted in the array, is shown in Fig. 5.6.1. Very closely similar readings were obtained for the other dipoles. The results demonstrate that the matching holds over at least a band of 100 MHz to 150 MHz.

For the remaining tests, the antenna was mounted in the field site on top of a rotary mast provided with plotting facilities for obtaining antenna patterns. A fixed outside transmitter was used and the outputs of dipole pairs were measured using a vector voltmeter.

First, a set of readings were obtained on one dipole pair (nos. 1 & 16) along with the remaining dipoles removed. Amplitude and polar patterns were plotted for the three frequencies across the band (137 MHz, 127 MHz and 117 MHz). These are recorded in Fig. 5.6.2A-C (azimuth) and Fig. 5.6.5A-C (phase).

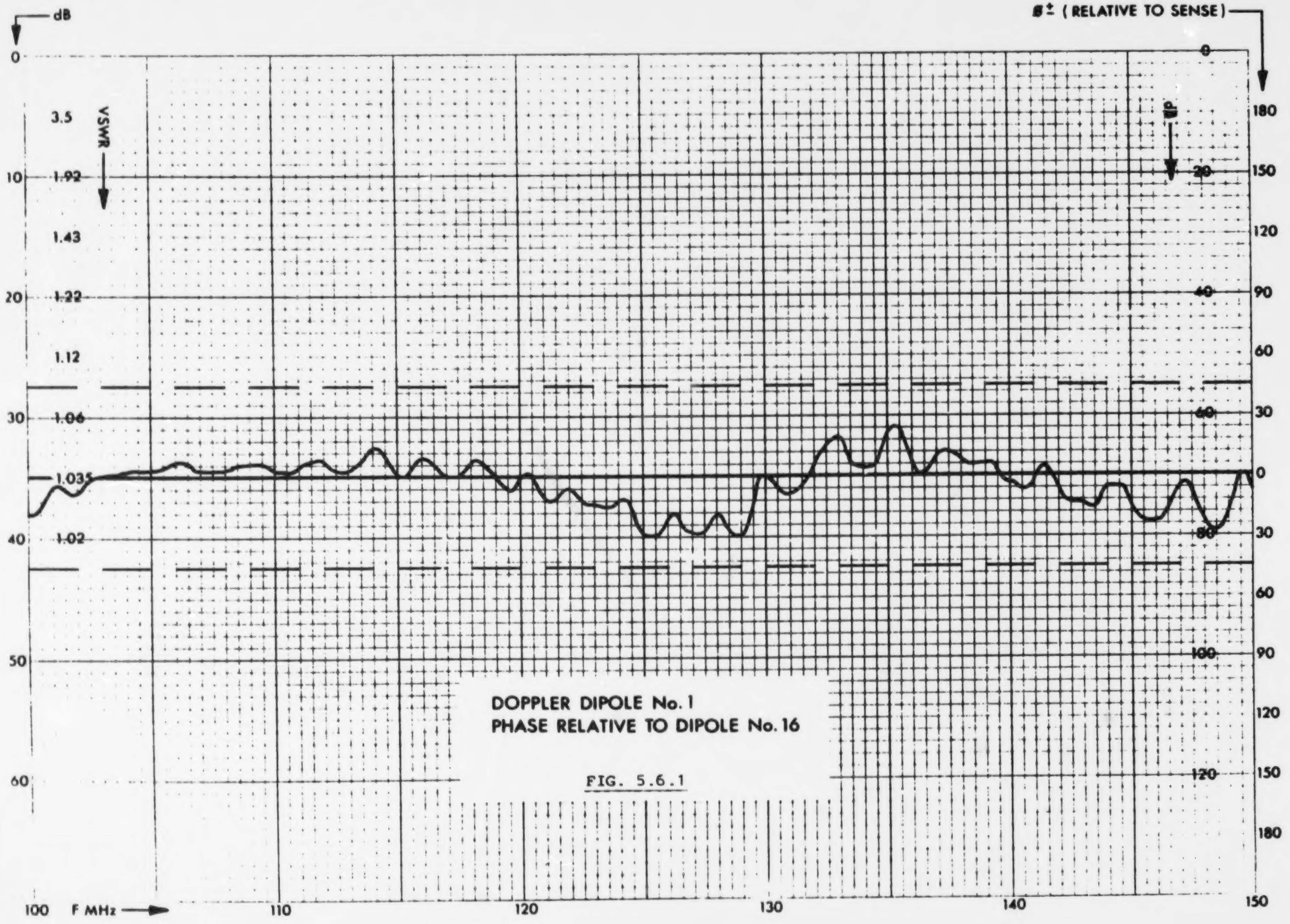
Next, the remaining 14 dipoles were replaced in the array and the readings were repeated to show the expected performance of the array under normal operating conditions (see Figs. 5.6.3A-C and 5.6.4A-C).

The object of the two sets of polar patterns was to show the influence of the mutual coupling between the dipoles in the array. The results of these tests were considered quite satisfactory, although warnings were taken on two specific observations:

1) The output fluctuation of a dipole may reach up to 12 dB, peak to peak, which may have influence on the threshold level.

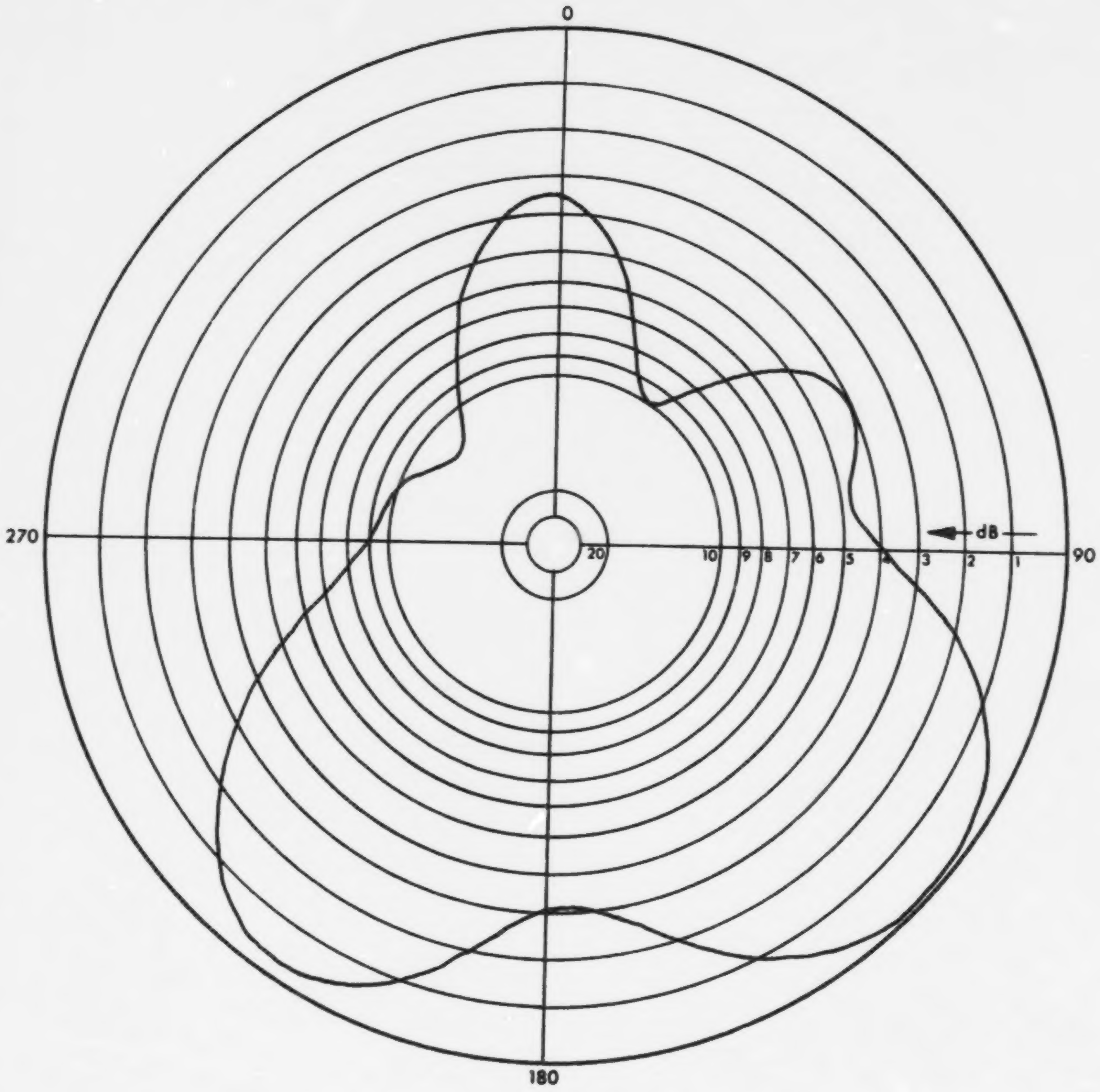
2) The phase fluctuation of a dipole pair reaches uncomfortably close to 180° which may cause spot problems with the phase detector.

The overall effects of these factors will have to be observed in the complete system.



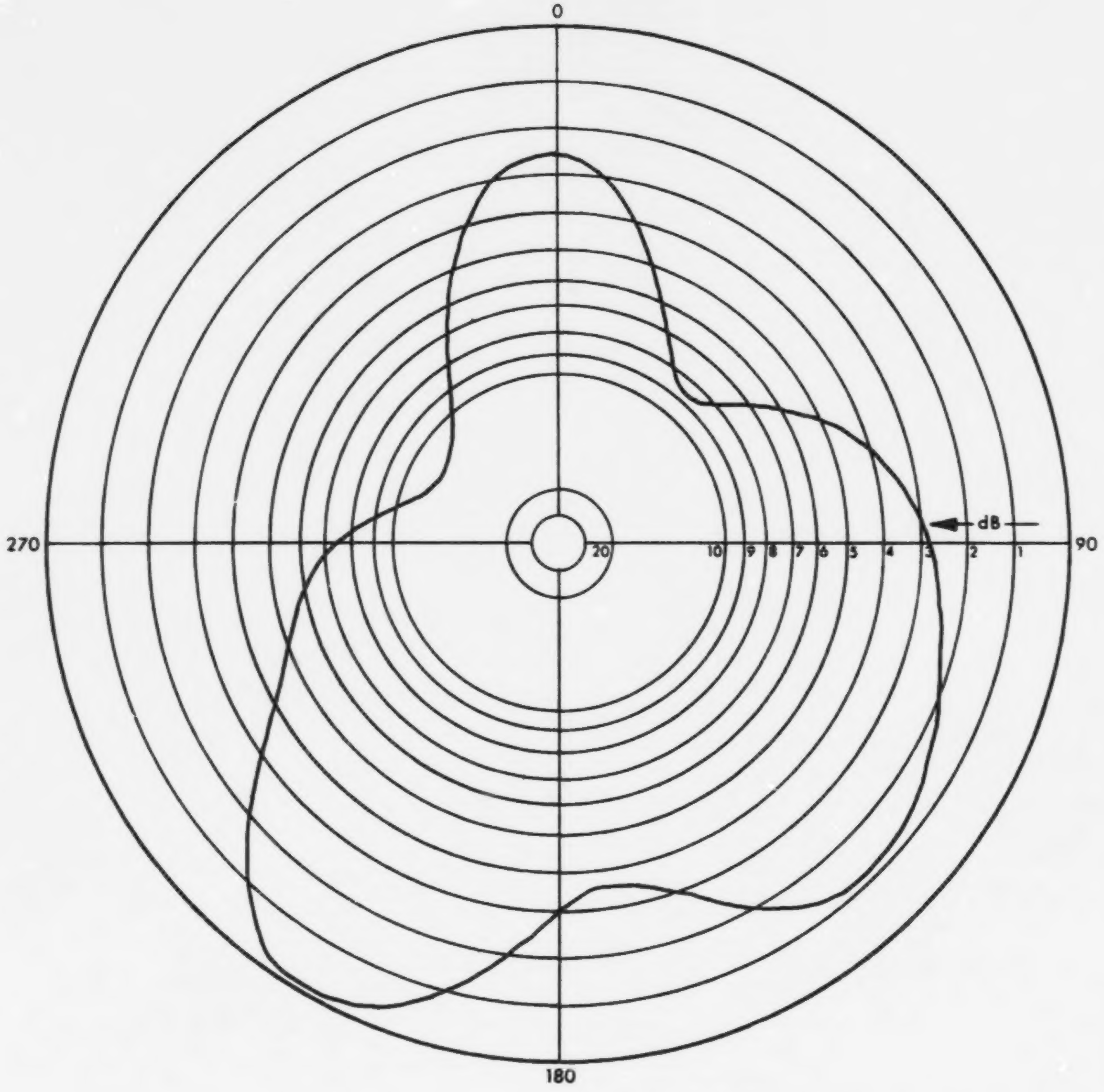
DOPPLER DIPOLE No. 1
PHASE RELATIVE TO DIPOLE No. 16

FIG. 5.6.1



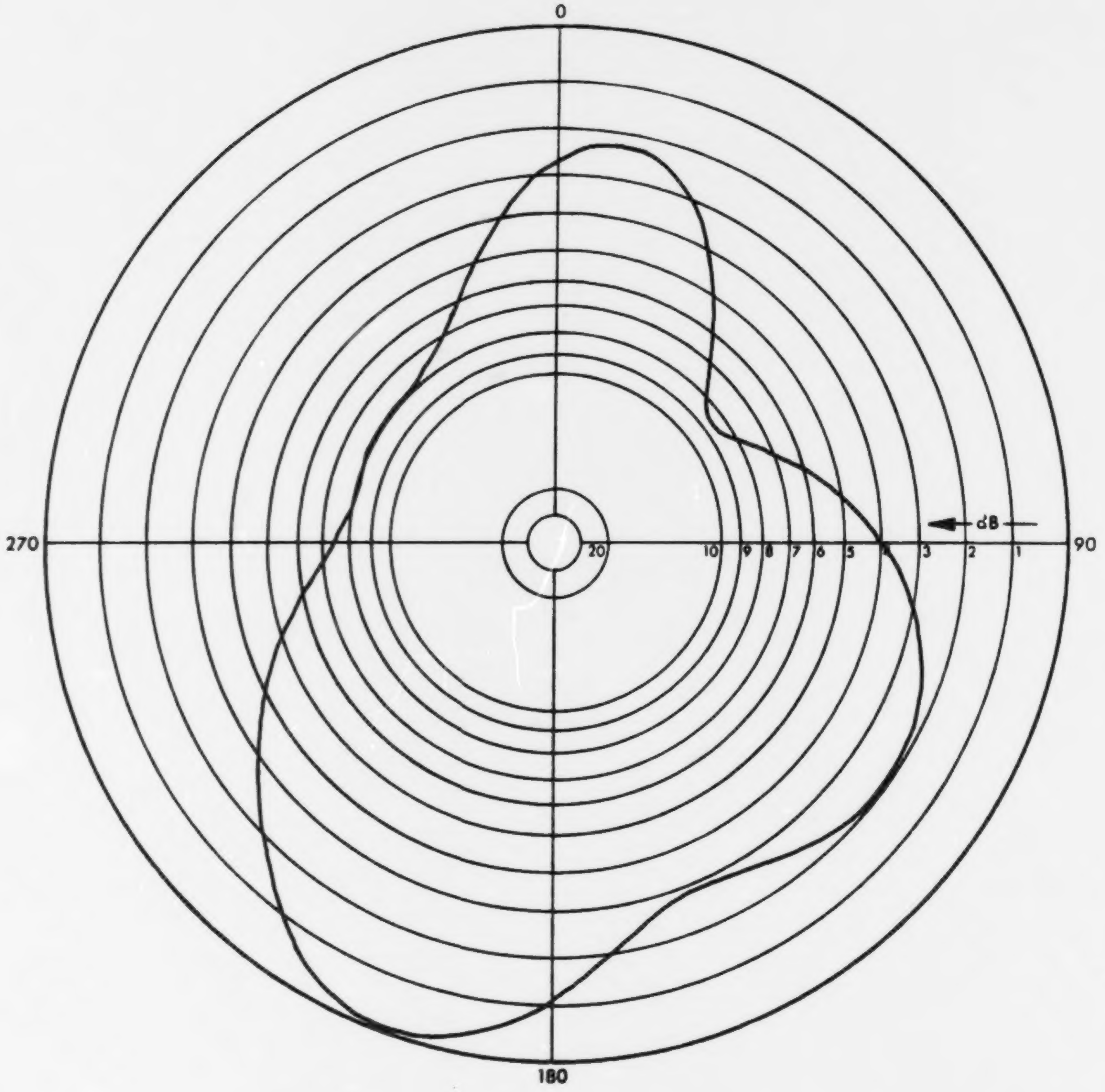
Dipole #1 output in dB versus azimuth
with dipole #16 terminated in 75Ω
14 other dipoles physically removed

FIG. 5.6.2A - 137 MHz AZIMUTH POLAR PATTERN



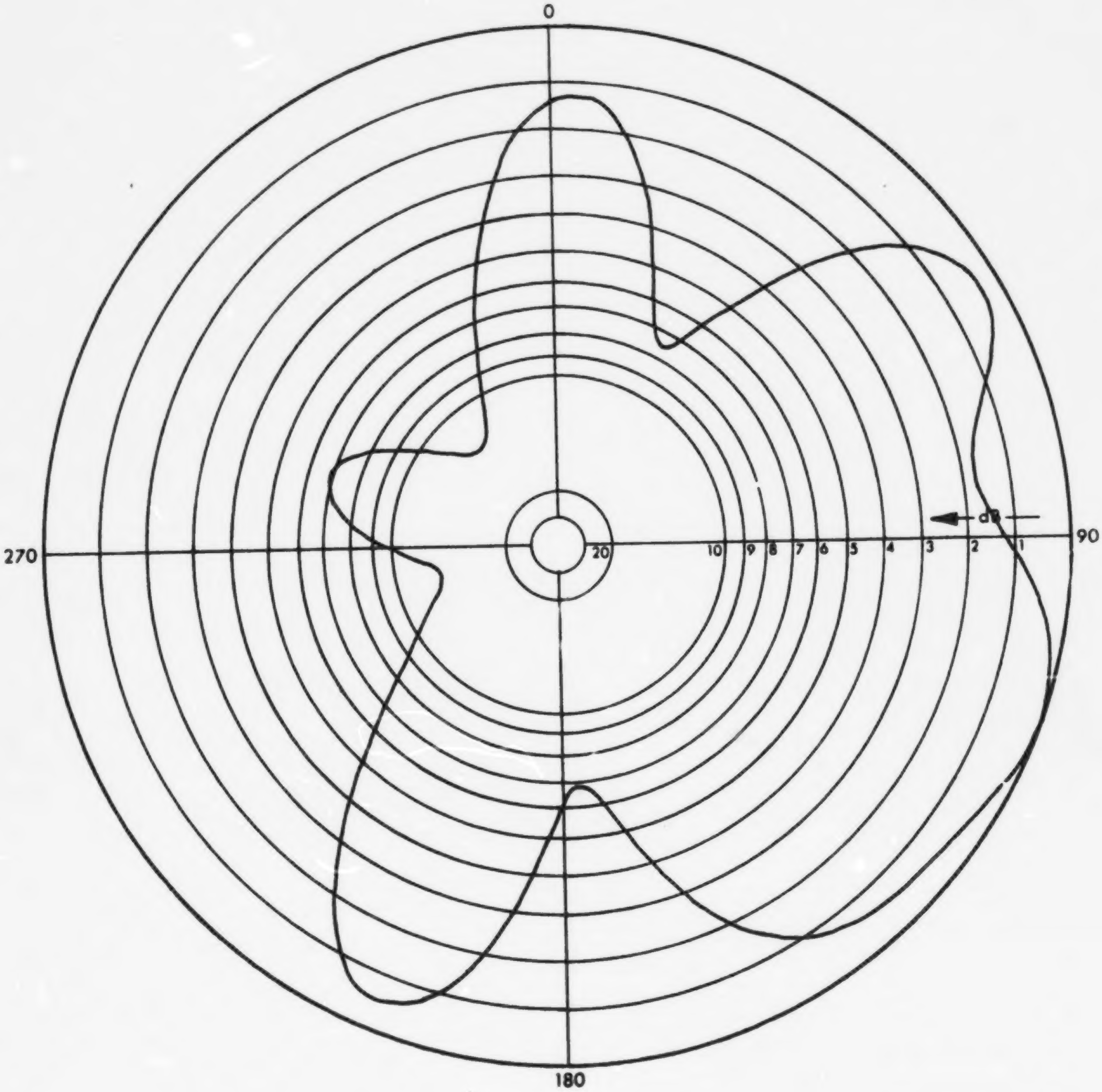
Dipole #1 output in dB versus azimuth
with dipole #16 terminated in 75Ω
14 other dipoles physically removed

FIG. 5.6.2B - 127 MHz AZIMUTH POLAR PATTERN



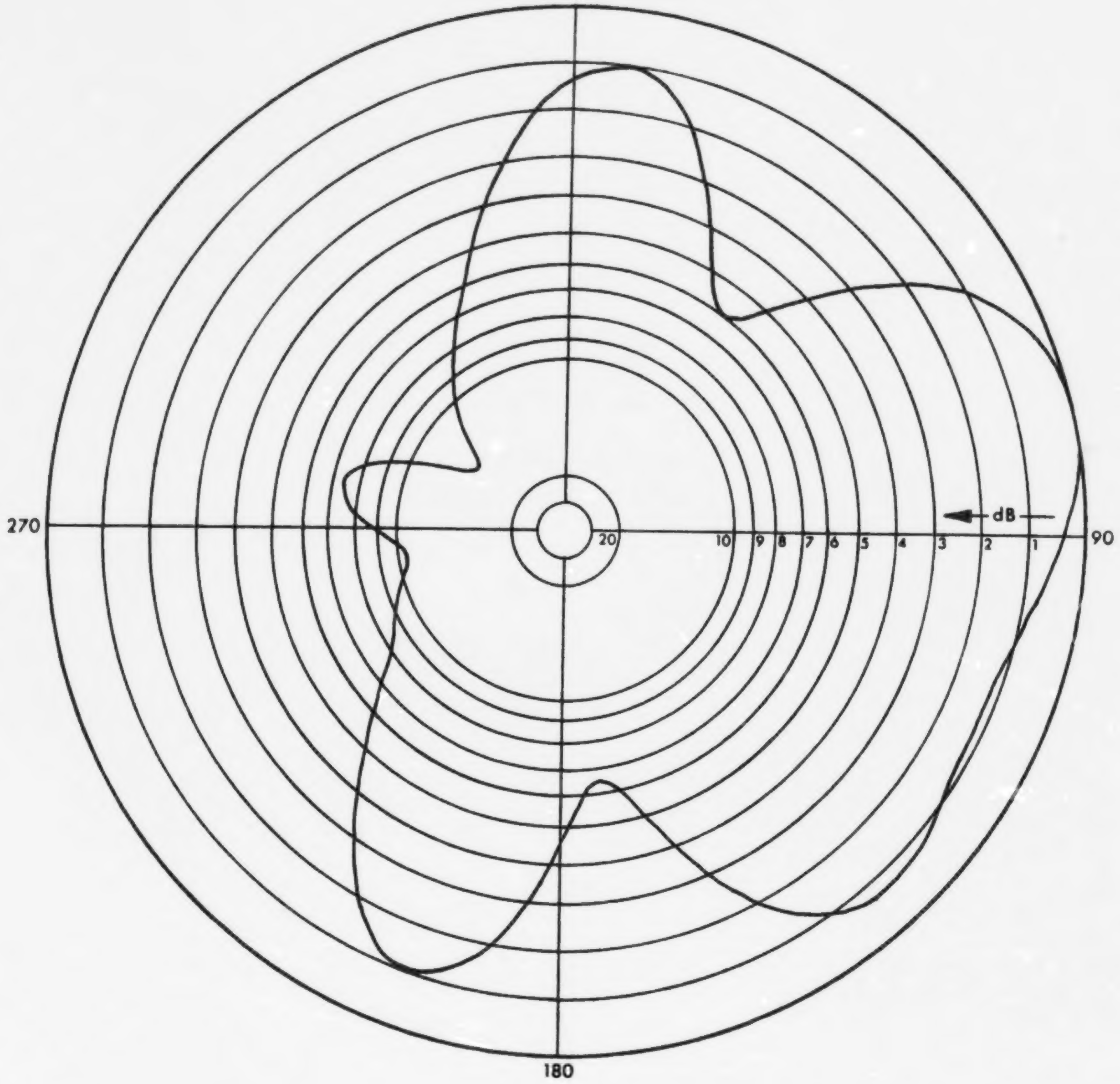
Dipole #1 output in dB versus azimuth
with dipole #16 terminated in 75Ω
14 other dipoles physically removed

FIG. 5.6.2C - 117 MHz AZIMUTH POLAR PATTERN



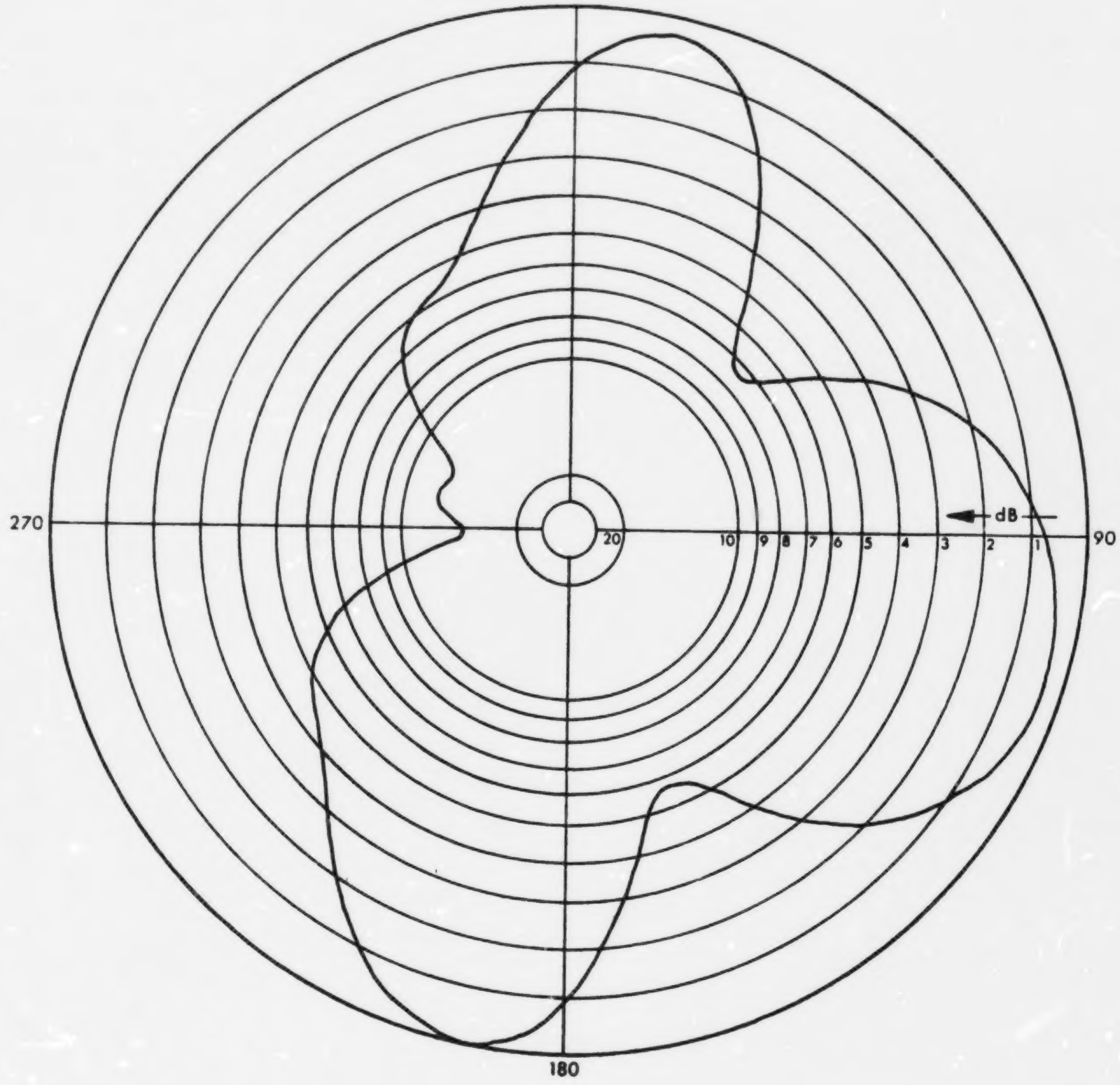
Dipole #1 output in dB versus azimuth
with 15 other dipoles terminated in 75 Ω

FIG. 5.6.3A - 137 MHz AZIMUTH POLAR PATTERN



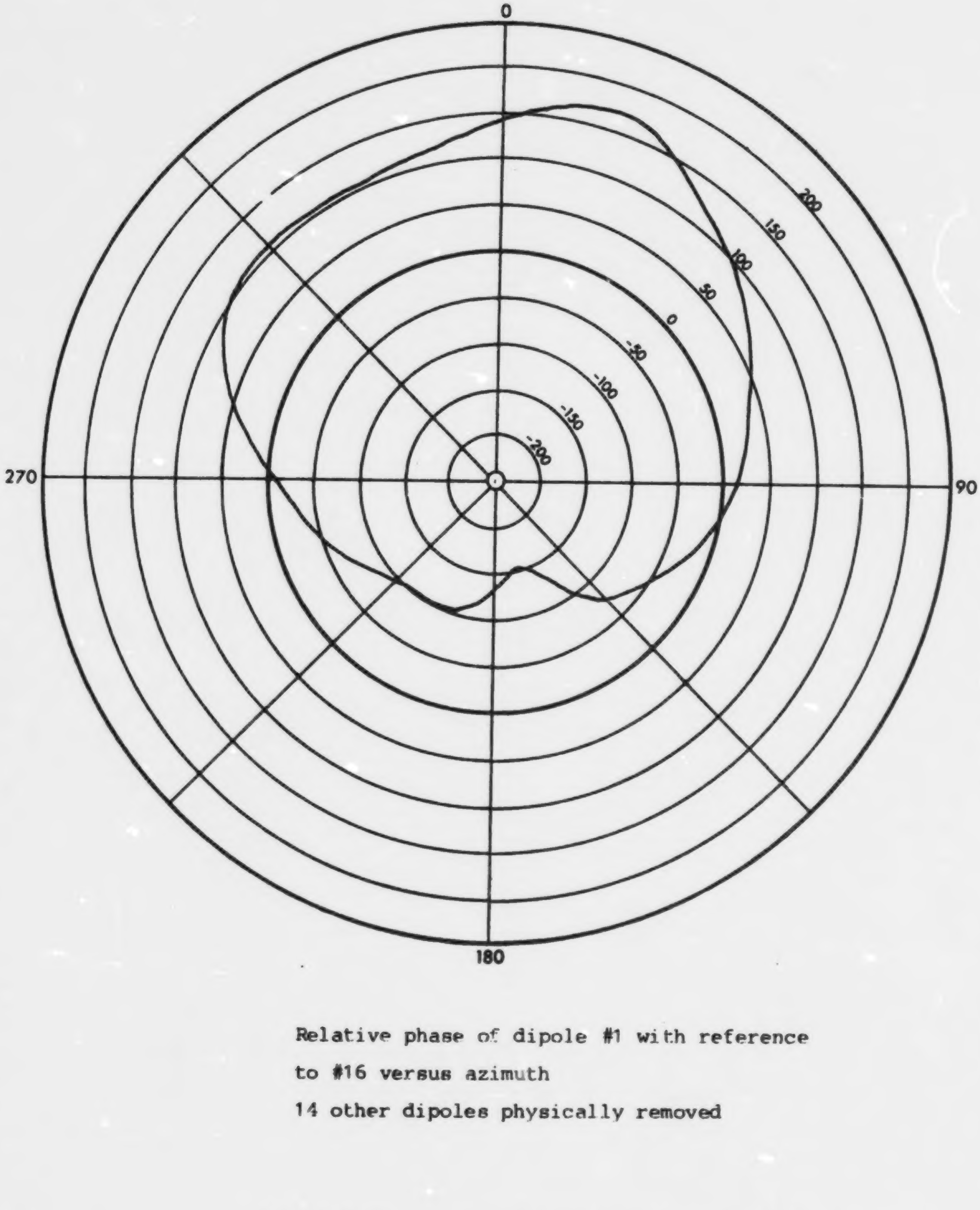
Dipole #1 output in dB versus azimuth
with 15 other dipoles terminated in 75 Ω

FIG. 5.6.3B - 127 MHz AZIMUTH POLAR PATTERN



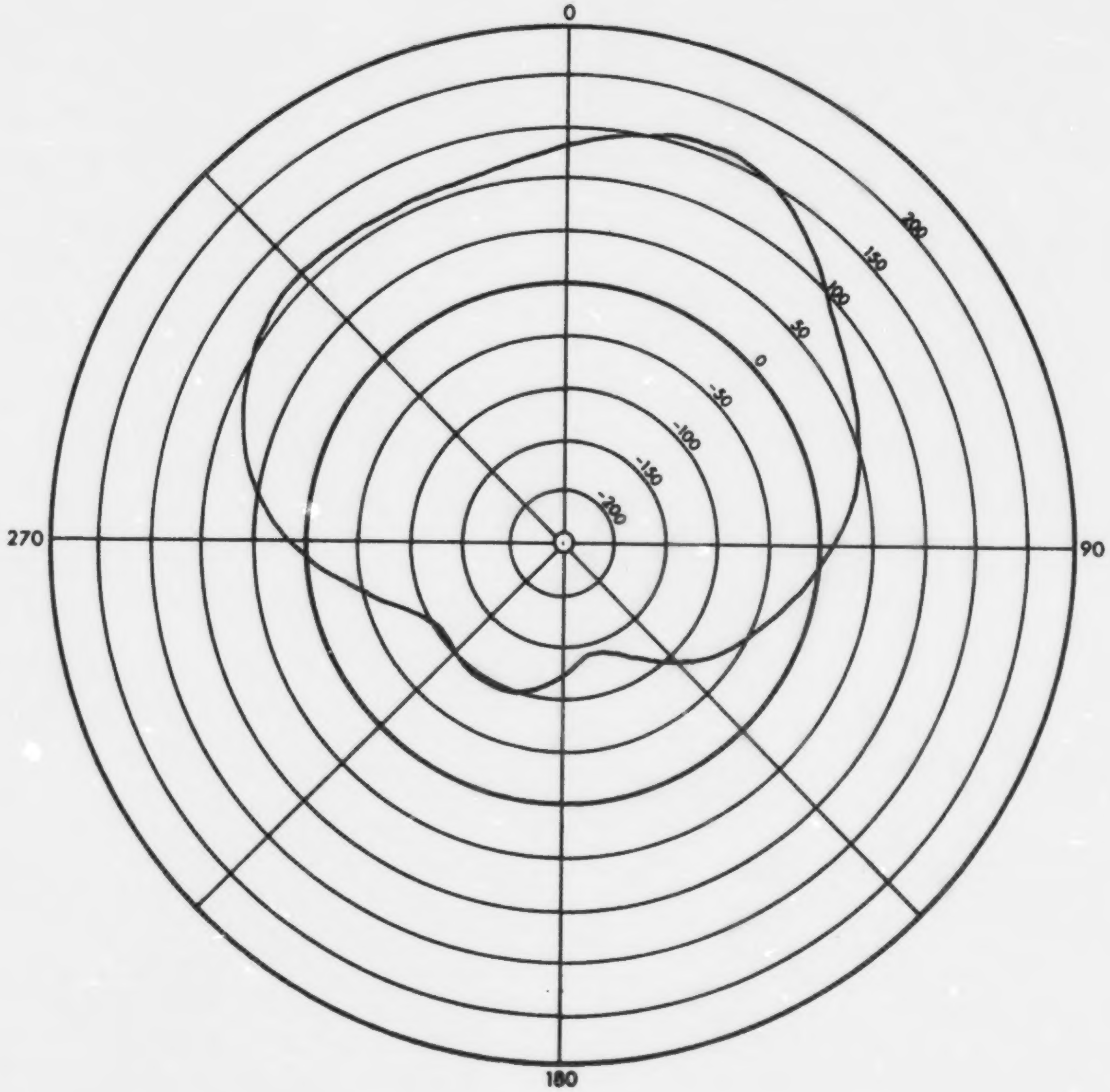
Dipole #1 output in dB versus azimuth
with 15 other dipoles terminated in 75Ω

FIG. 5.6.3C - 117 MHz AZIMUTH POLAR PATTERN



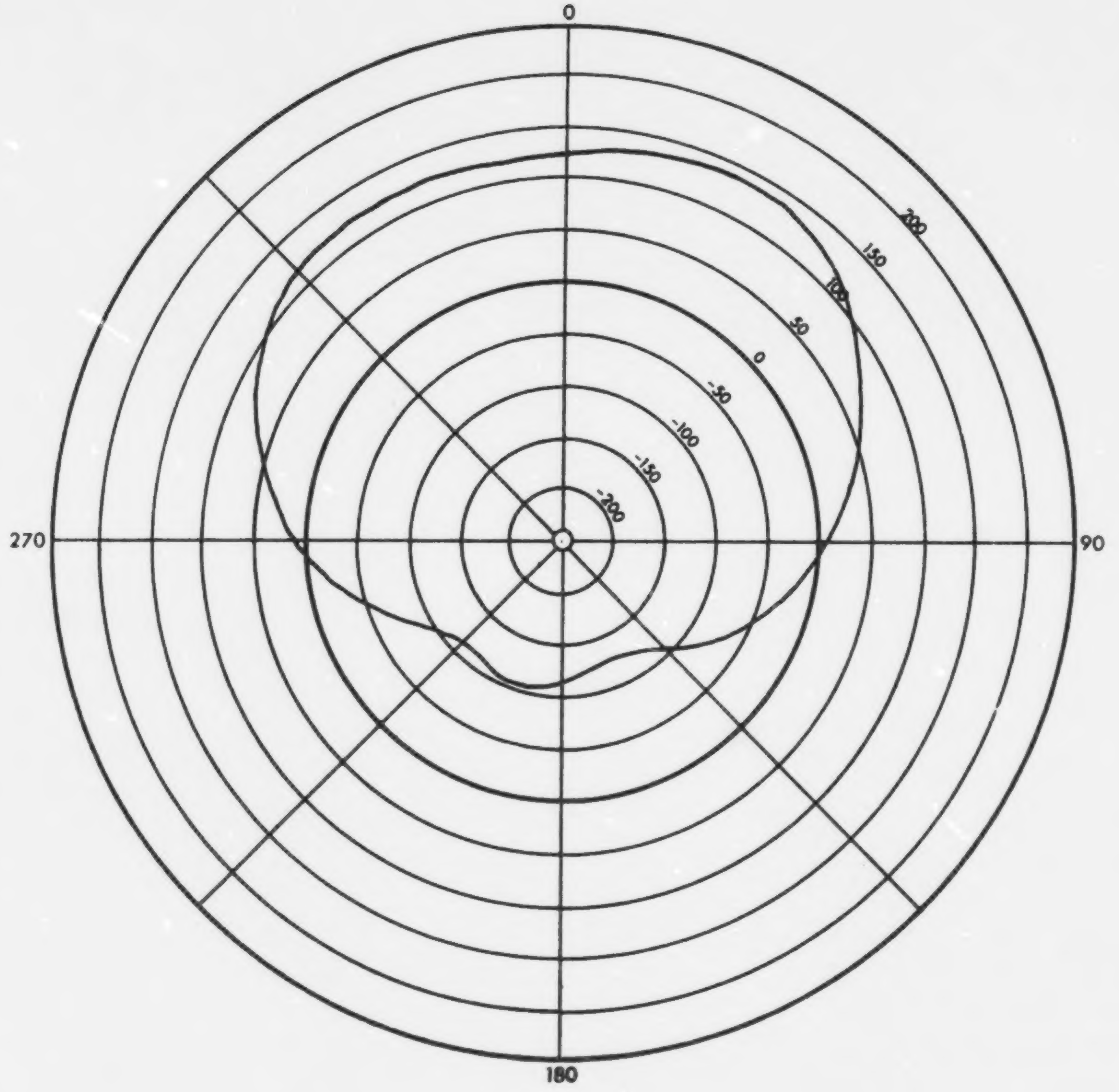
Relative phase of dipole #1 with reference
to #16 versus azimuth
14 other dipoles physically removed

FIG. 5.6.4A - 137 MHz PHASE DIFFERENCE POLAR PATTERN



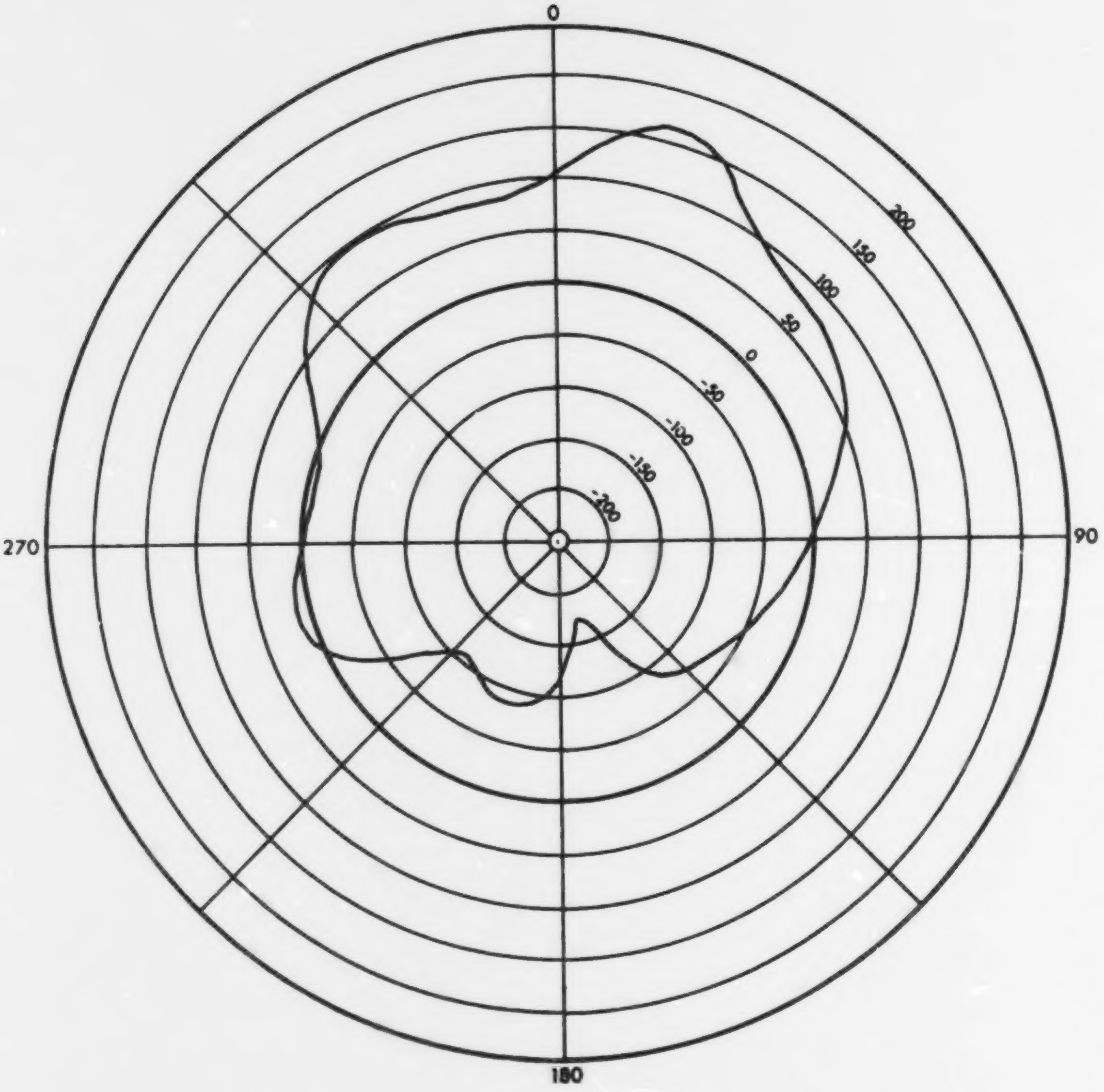
Relative phase of dipole #1 with
reference to #16 versus azimuth
14 other dipoles physically removed

FIG. 5.6.4B - 127 MHz PHASE DIFFERENCE POLAR PATTERN



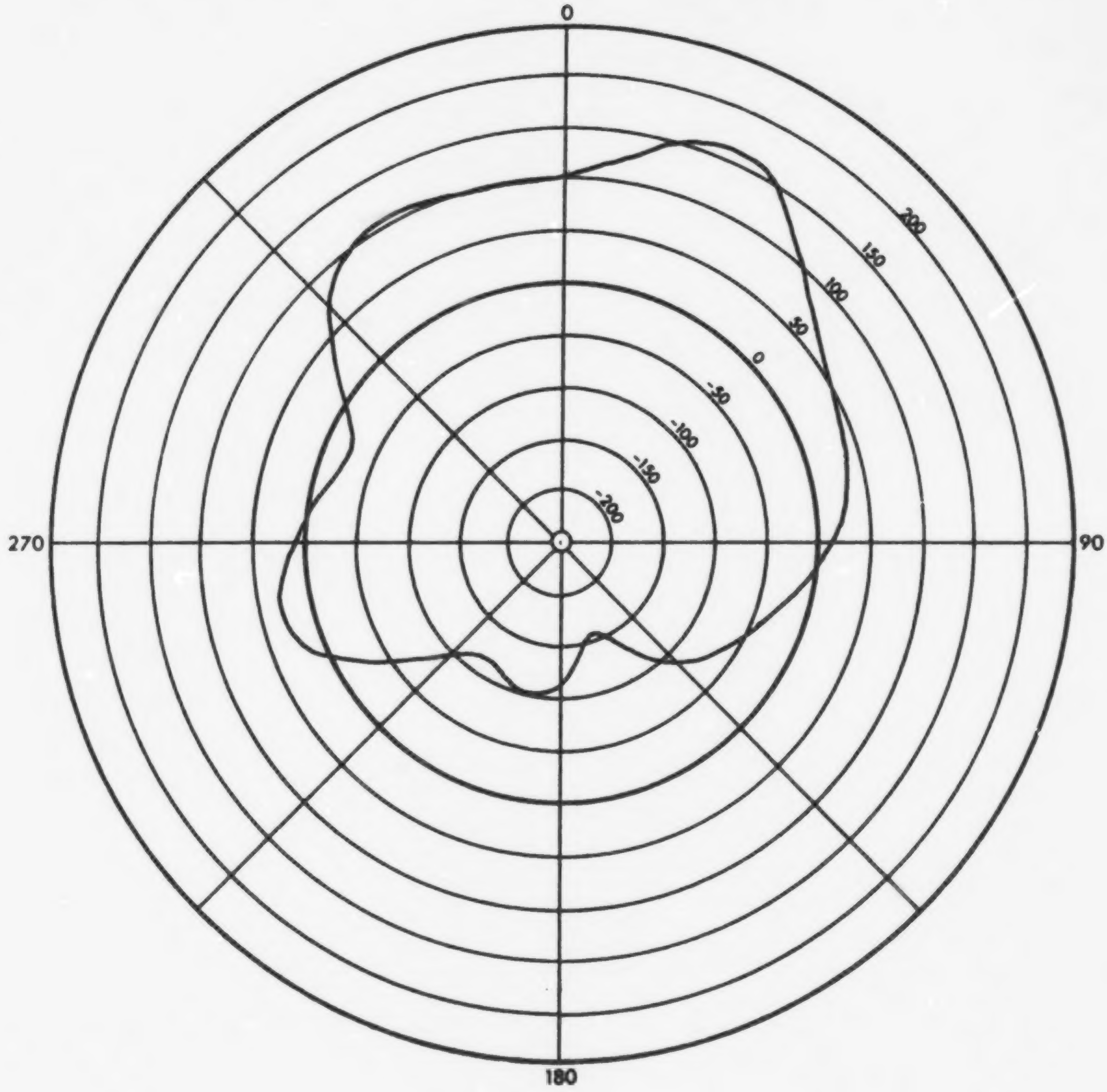
Relative phase of dipole #1 with
reference to #16 versus azimuth
14 other dipoles physically removed

FIG. 5.6.4C - 117 MHz PHASE DIFFERENCE POLAR PATTERN



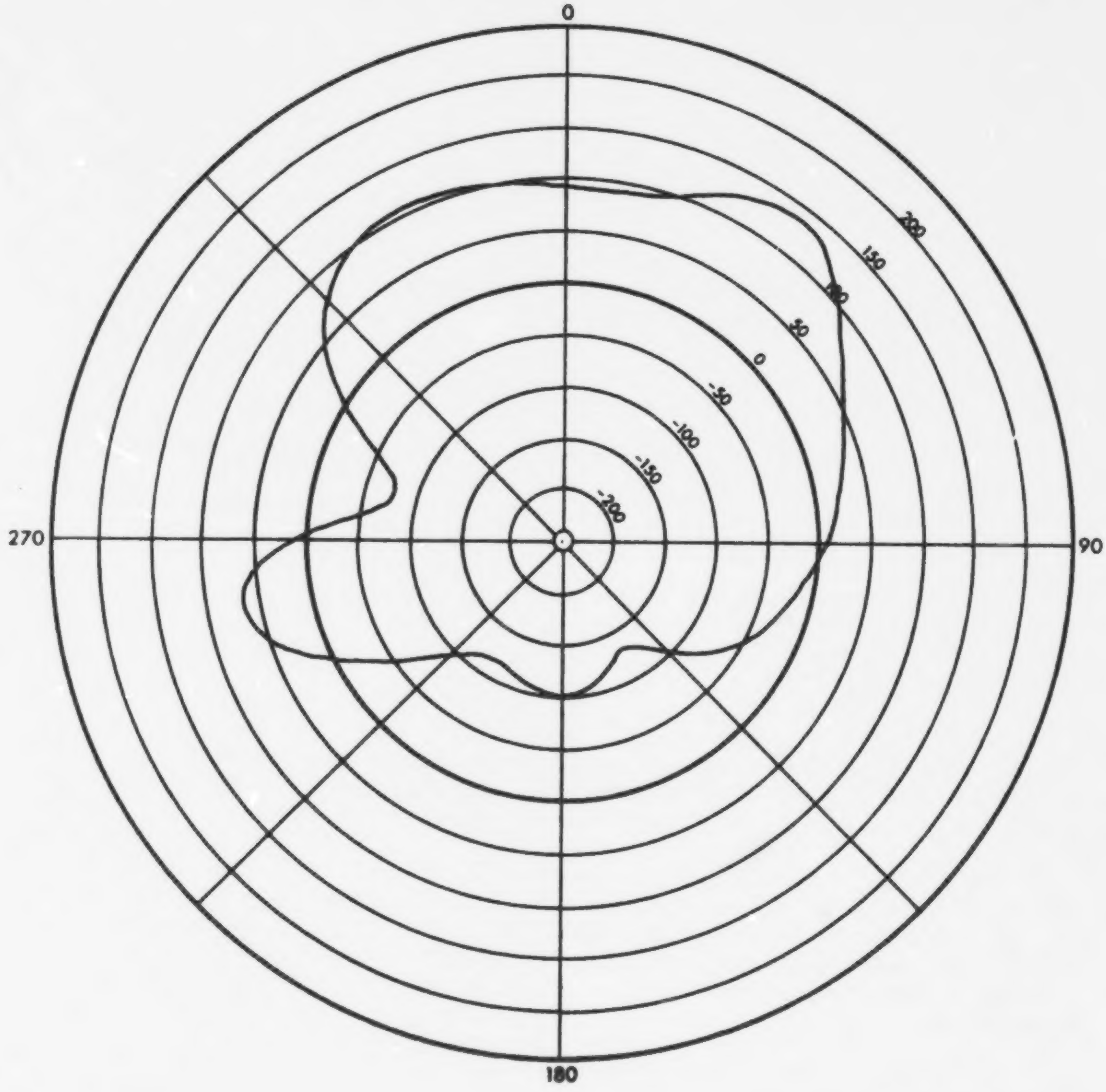
Relative phase of dipole #1 with
reference to #16 versus azimuth
14 other dipoles terminated in 75 Ω

FIG. 5.6.5A - 137 MHz PHASE DIFFERENCE POLAR PATTERN



Relative phase of dipole #1 with
reference to #16 versus azimuth
14 other dipoles terminated in 75 Ω

FIG. 5.6.5B - 127 MHz PHASE DIFFERENCE POLAR PATTERN



Relative phase of dipole #1 with
reference to #16 versus azimuth
14 other dipoles terminated in 75Ω

FIG. 5.6.5C - 117 MHz PHASE DIFFERENCE POLAR PATTERN

5.7 Test Injection Circuit (see Fig. 5.7.1)

The purpose of the test injection circuit is to test the operation of the overall DF system. Four RF test sources are provided at 45°, 135°, 225° and 270° locations. These sources are located eccentrically within the dipole ring array at the first crossover of the supporting ground plane cable. In the sixteen element array this position is 0.78 in. from the closest dipole.

In order to determine the required signal levels the coupling between a short test injection antenna and a DF dipole was measured on the simulated antenna ground plane.

The test injection antenna was a length of 16 ga wire soldered to a female type N bulkhead connector, UG625B/U.

No attempt was made to match the impedance of the electrically short monopole to the 50 ohms test equipment. For the final model, a suitably sturdy and waterproof test injection antenna can be made using a UG1095A/U type N panel jack.

The coupling between the test injection antenna and the closest dipole was measured for different lengths of the test antenna monopole. For antenna lengths of 6, 4 and 2 inches the coupling was 40, 50 and 55 dB respectively.

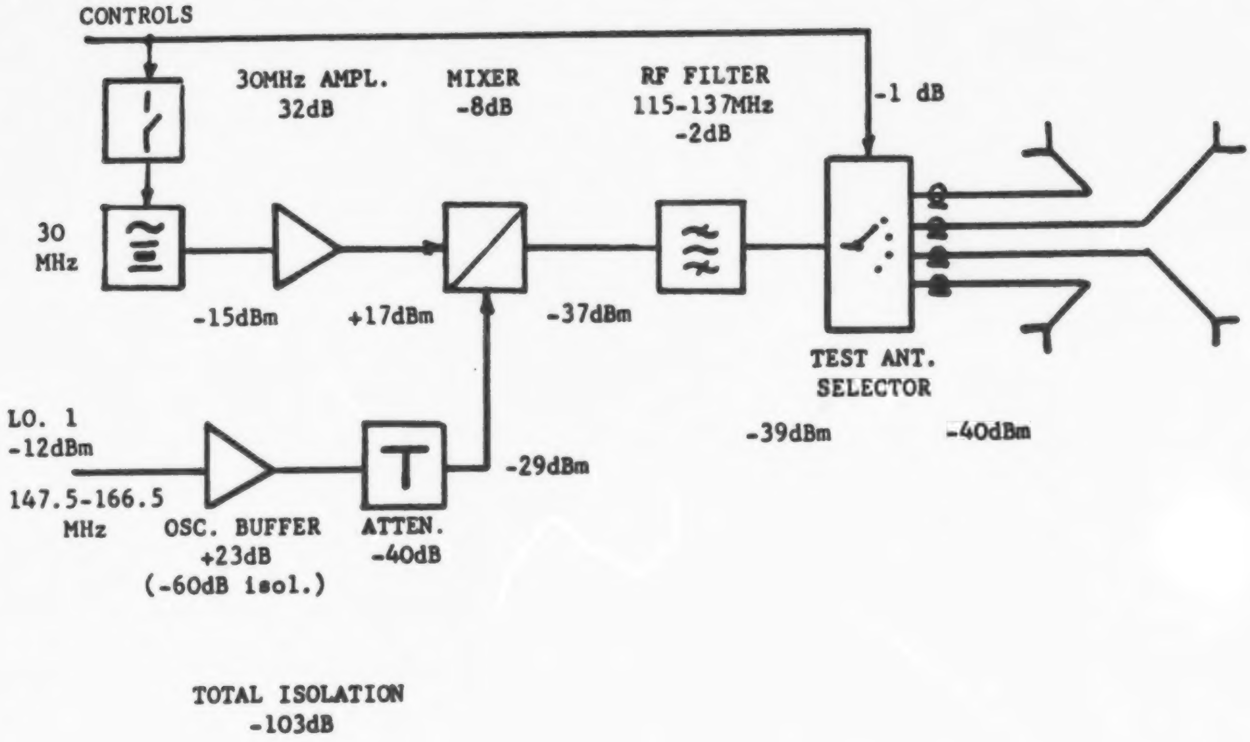
Using the 40 dB coupling value implies that the test injection antenna must be fed with a power level of -47 dBm to give a level of -87 dBm at the receiver input. This will provide a signal which is 20 dB above the minimum sensitivity level of the receiver.

The RF test injection signal must be tuned to the same frequency as the DF receiver. It is generated by mixing a 30 MHz synthetic IF signal with the 1st local oscillator signal. The simulated RF signal is then filtered, amplified and switched to the proper test injection antenna by means of a 4 position pin diode switch (see the attached block diagram).

In the design of the Test Injection circuit, it is extremely important to avoid leaks of the simulated RF signal via any path other than the selected test injection antenna. Adequate shielding and filtering must be provided for the test signal generator module and the line from the first local oscillator must be isolated in the reverse direction by some 40 dB more than the loop gain round the antenna circuit. Consequently, a high isolation buffer amplifier is supplemented by an attenuator in the local oscillator path to the 'RF port' of the double balanced mixer. This is a low-level port and the amplifier gain is allowed to make up for the additional attenuation. The 'LO port' is fed at a high level from the 30 MHz crystal oscillator source. Here, the isolation is less important as the 30 MHz component can be more easily suppressed by the band-pass filter.

There is one inherent spurious frequency generated inside the band, the 4th harmonic of 30 MHz or 120 MHz. This spurious is unavoidable, being generated in the mixer. It is proposed to adjust the drive level to the mixer in order to minimize this effect.

Note that the Test Injection Circuit is made up of individual circuit blocks identical to those used in the DF Receiver Front End for which they were developed and proved.


CONTROLS
30MHz AMPL.
32dB
MIXER
-8dB
RF FILTER
115-137MHz
-2dB
-1 dB
30
MHz
-15dBm
+17dBm
-37dBm
TEST ANT.
SELECTOR
-39dBm
-40dBm
LO. 1
-12dBm
147.5-166.5
MHz
OSC. BUFFER
+23dB
(-60dB isol.)
ATTEN.
-40dB
-29dBm
TOTAL ISOLATION
-103dB

TEST SIGNAL INJECTION

BLOCK DIAGRAM

FIG. 5.7.1

6. RECEIVER AND BEARING PROCESSOR

6.1 DF Receiver Front End Prototype

6.1.1 Scope

This report describes the performance of the recently modified PCB performing the Front End function of the DF receiver channels. Modifications to the original design consisted of:

i. improvement of the RF filters by using coils of a higher Q, in order to reduce the insertion losses.

ii. replacing the original IF filter (30 MHz) using ferrite cores by one with open coils provided with tuning slugs.

iii. careful revision of the ground areas to improve shielding and reduce stray inductances.

6.1.2 Composition

DF Rx Front End consists of the following main components:

i.	1st RF filter	RF Section
ii.	RF Amplifier	
iii.	2nd RF filter	
iv.	Mixer	
v.	1st IF filter (30 MHz)	IF Section
vi.	IF Amplifier (30 MHz)	
vii.	LO Buffer	

6.1.3 The RF Section

1st RF Filter: The first filter is a single lumped LC filter with maximum flat response and with a good VSWR of 10 dB. Good VSWR is necessary for channel matching as a signal coming from the antenna is fed to RF amplifier through this filter.

Characteristics:

Centre Frequency : 127 MHz

3 dB Bandwidth : 117-137 MHz = 20 MHz

IL : ≤0.5 dB

VSWR : 10 dB

RF Amplifier: This is a flat gain amplifier in the RF range, with a gain of 23 dB.

Mosfet 3N200 is used to achieve good back to front isolation of 40 dBm and more. The amplifier works in class A up to the input level of -10 dBm (our requirement is -47 dBm max.)

2nd RF Filter: This is also a lumped LC filter with five sections:

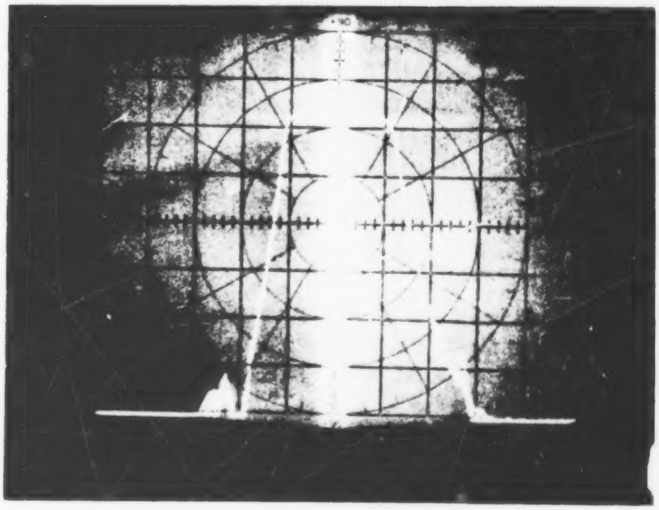
Centre Frequency : 127 MHz

3 dB Bandwidth : 20 MHz

IL : ≤3 dB

The filter is a linear phase filter which is necessary to match the two DF channels in phase.

The overall performance of 1st RF filter, RF amplifier and 2nd RF filter is as shown below:



Centre Freq. : 127 MHz

3 dB BW : 20 MHz

IL : ≤3dB

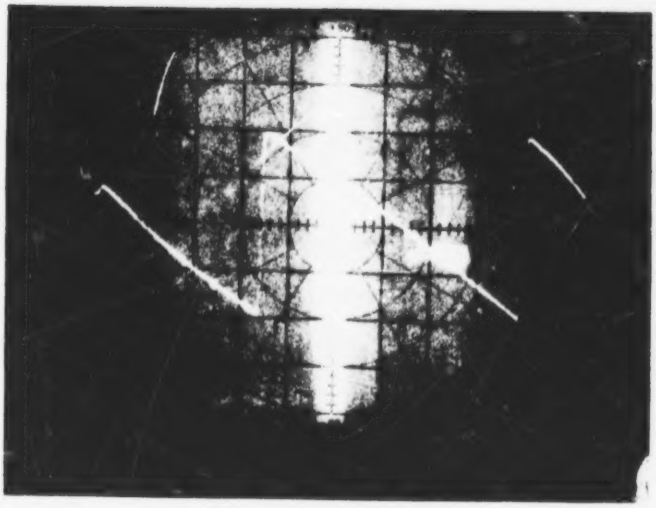
Scale:

Amp. Resp. : 10 dB/cm

Full Sweep : 100 MHz

FIG 6.1.1

2nd RF FILTER - AMPLITUDE RESPONSE



Centre Freq. : 127 MHz

Scale:

Phase Resp. : 90°/cm

Full Sweep : 20 MHz

FIG. 6.1.2

2nd RF FILTER - PHASE RESPONSE

6.1.4 Mixer

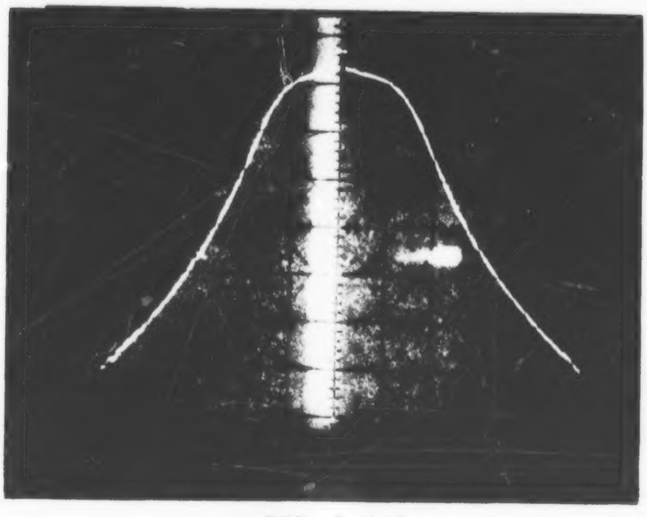
The mixer used for the first conversion is the type SRA-1H by Minicircuits with an oscillator injection level of +17 dBm.

6.1.5 The IF Section

The IF filter is again a lumped LC symmetrical filter with linear phase response of 30 MHz with a bandwidth of 800 kHz and IL ≤8 dB.

The IF Amplifier for 30 MHz has a gain of 32 dB and is linear up to the input of -10 dB (our requirement is -49 dB max.

The overall performance of IF filter and IF amplifier is shown below.



Centre Freq. : 30 MHz

3 dB BW : 80 kHz

IL : ≤8 dB

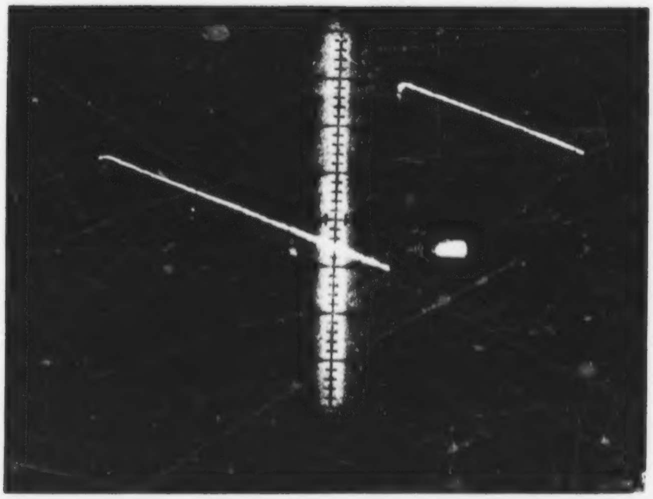
Scale;

Amp. Resp. : 10 dB/cm

Full Sweep : 5 MHz

FIG. 6.1.3

1st IF FILTER - AMPLITUDE RESPONSE



Centre Freq. : 30 MHz

Scale:

Phase Resp. : 90°C/cm

Full Sweep : 1 MHz

FIG. 6.1.4

1st IF FILTER - PHASE RESPONSE

6.1.6 The LO Buffer

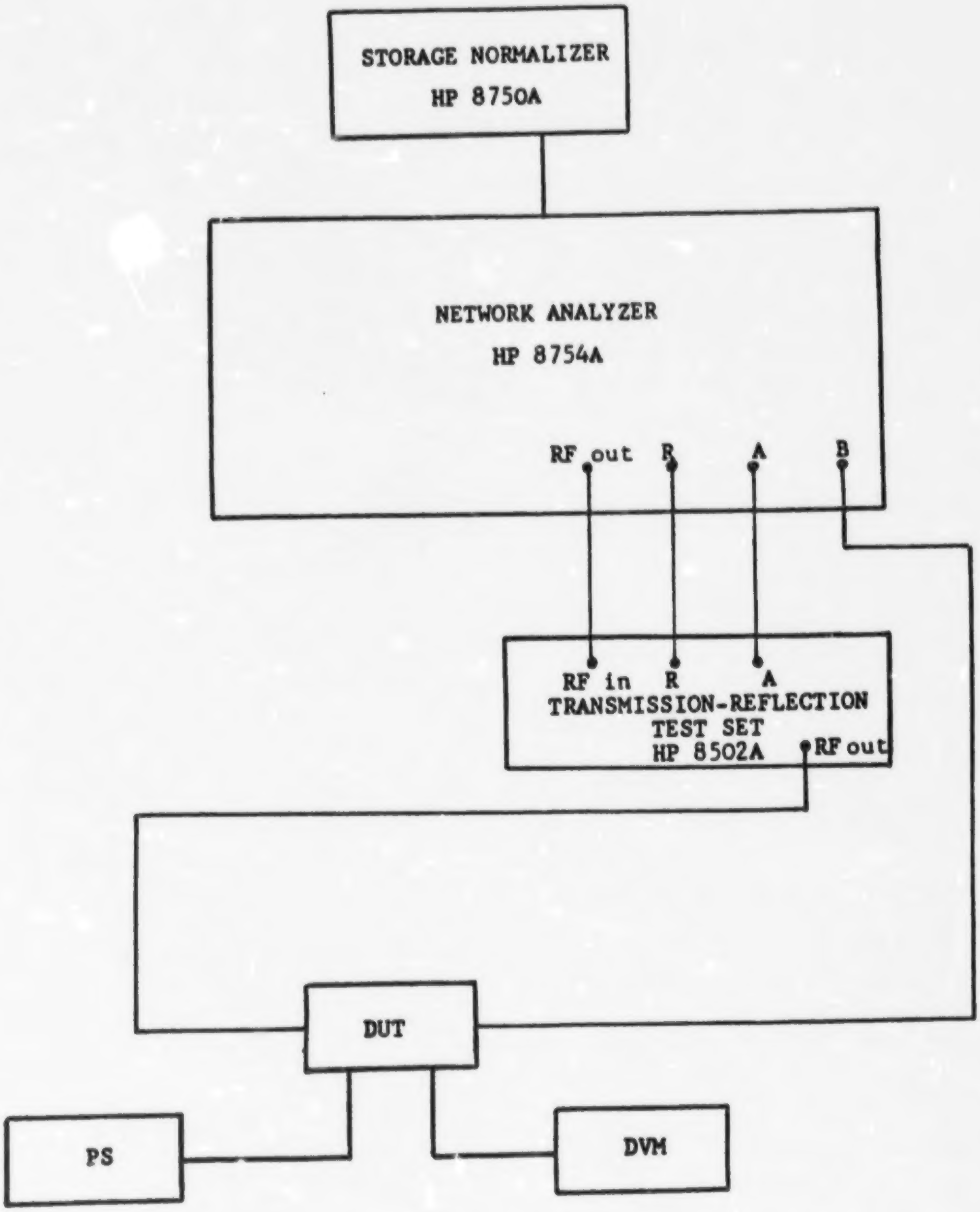
Since back to front isolation is a pre-requisite, the LO buffer uses the sum circuit as the RF amplifier except for using 2N5943 instead of BFP96 giving a gain of 20 dB which is sufficient to bring the LO level up to +17 dB. Its gain is controlled by varying the 2nd gate bias and the emitter feedback of the second stage.

6.1.7 Conclusion

From the phase response of the two sections, it is clear that the two DF channels can be matched very easily.

FIG. 6.1.5

TEST CIRCUIT FOR FUTURE ANALYSIS


STORAGE NORMALIZER
HP 8750A
NETWORK ANALYZER
HP 8754A
RF out
R
A
B
RF in
R
A
TRANSMISSION-REFLECTION
TEST SET
HP 8502A
RF out
DUT
PS
DVM

All the tests are performed using HP8754A Network Analyser with the above set up. A description of the above set can be found in HP application literature.

6.2 Tuned Amplifier for 30 MHz and 2.2 MHz for ADF System

In the previous stages of design, it was decided to design these 30 MHz and 2.2 MHz amplifiers with AGC networks for emergency and audio channels.

For this purpose, two approaches were taken into consideration:

1. Amplifier with external AGC network

   i.e. 'T' or 'π' network with PIN diode as attenuators

2. With internal AGC network

Due to cost estimation and area required for AGC network on PCB, we came to the conclusion not to go along with the first approach.

In the second approach we decided to use dual gate FET as an amplifier and AGC network for the first stages. It is preferred to use it as a first stage to receive better S/N ratio.

Dual gate FET's have more advantages than ordinary FET's, e.g. special back to back diodes are diffused directly into the MOS pellet and are electrically connected between each insulated gate and the FET's source. The diodes effectively bypass any voltage transient which exceeds approximately ±10 volts (to protect the gates). These diodes also give FET wide input signal dynamic range. In addition, the low junction capacitance of these diodes adds little to the total capacitance shunting the signal gate.

Therefore, it is useful for a wide variety of r.f. amplifier applications at frequencies up to 500 MHz.

The two serially connected channels with independent control gates give lower cross modulation.

The amplifier is designed with two stages: the first stage is FET and the second bipolar. Both stages are tuned to proper CW frequencies, both the amplifiers are similar except resonant circuits.

The gain response of the amplifier is shown below:

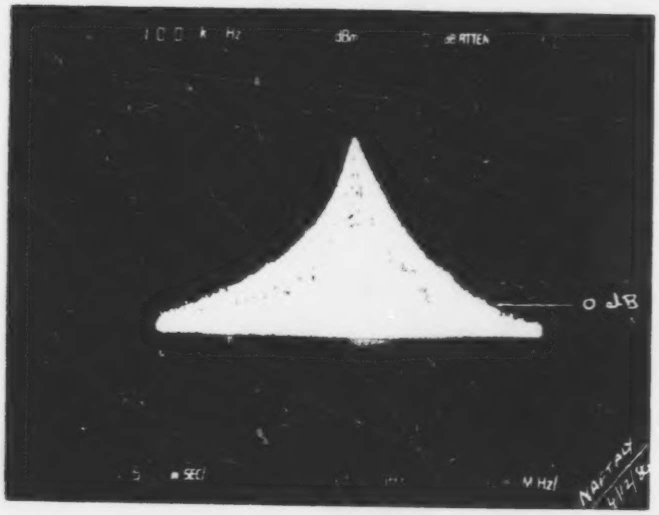


FIG. 6.2.1

30 MHz DF AMPLIFIER FREQUENCY RESPONSE

In general, gain up to 15 dB can be easily obtained from the first FET stage. The second stage is required to obtain more gain. If the need arises, it is possible to obtain a gain of 45 dB with this two stage amplifier with AGC of 35 dB.

To have lower cross modulation is desirable to design with AGC gate voltage of +40 V DC.

CIRCUIT DIAGRAM

GAIN 32 dB

AGC CONTROL 38 dB

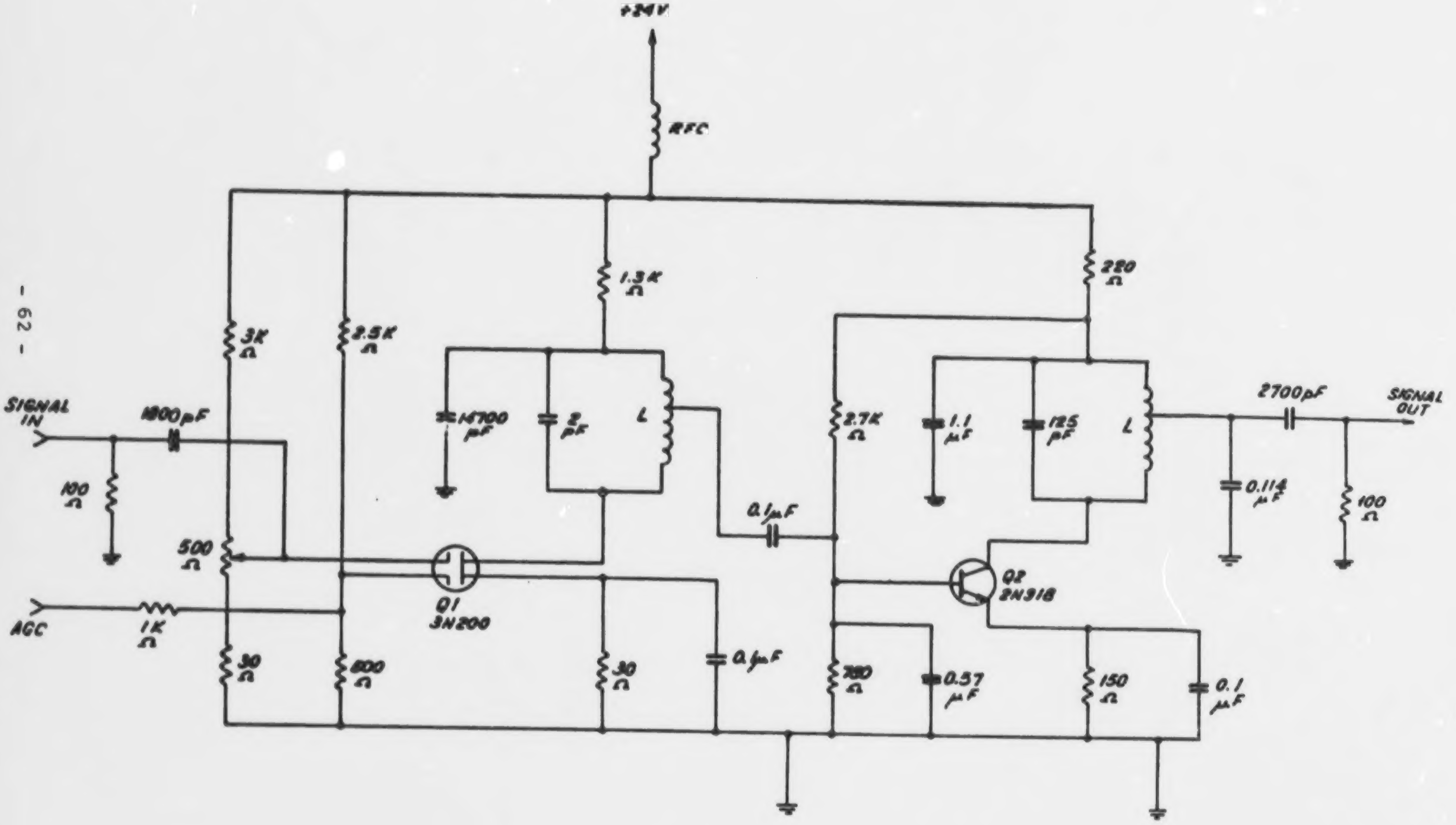

+24V
RFC
SIGNAL IN
1800 pF
100 Ω
500 Ω
3K Ω
2.5K Ω
AGC
1K Ω
30 Ω
800 Ω
Q1
3N200
1.3K Ω
14700 μF
2 pF
L
30 Ω
0.1 μF
0.1 μF
220 Ω
2.7K Ω
1.1 μF
125 pF
L
Q2
2N918
780 Ω
0.57 μF
150 Ω
0.1 μF
2700 pF
SIGNAL OUT
0.114 μF
100 Ω

FIG. 6.2.2

30 MHz DF AMPLIFIER WITH AGC

The graph below shows AGC response to -ve voltage applied to AGC gate.

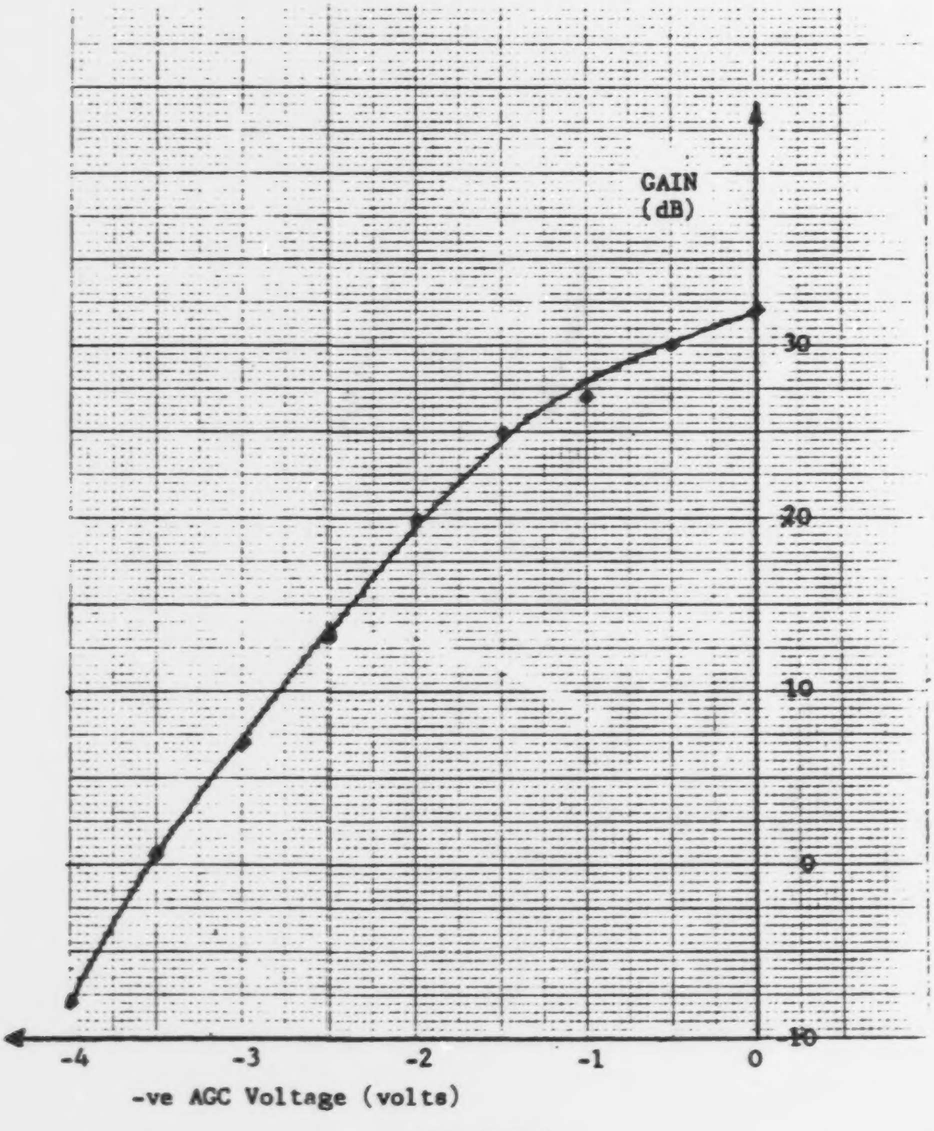


FIG. 6.2.3

30 MHz DF AMPLIFIER AGC RESPONSE

In system design, to obtain better S/N ratio, the AGC of 2.2 MHz amplifier will be applied before the AGC of 30 MHz amplifier.

6.3 Development of IF Amplifiers

The RF section for the Doppler Directional Finder operates as a triple conversion receiver employing three intermediate frequencies. The first IF section consists of two different amplifier stages separated by approximately 50 ft. of cable and operating on 30 MHz. Also included in this gain block, is a phase equalization network for matching the phase response in the two channels.

Figure 6.3.1 shows the schematic diagram for the first amplifier. The initial system design specified a gain of 30 dB minimum for this stage, it was possible to achieve a gain of 32 dB using two stages of amplification. This amplifier is preceded by the 30 MHz filter having an output impedance of 200 Ohms, therefore, the input impedance was designed to match to this load. The output feeds into approximately 50 ft. of cable with characteristic impedance of 50 Ohms. The interstage coupling impedance was chosen at 120 Ohms to facilitate another transformation from 200 to 50 Ohms impedance. Emitter degeneration, in the form of negative current feedback, was employed to improve stability and to decrease the influence of variations in transistor parameters on performance. However, the use of emitter degeneration tends to increase input impedance at these frequencies, therefore, negative voltage feedback was also employed to control the input impedance and fu ther enhance circuit stability. The output impedance is matched by use of transformers. Input return loss was measured at 22 dB while output at 30 dB, this is important to minimize reflection in the cable.

The second amplifier is shown in Fig. 6.3.2. A similar design method was used as in previous stage. The input and output impedance is specified at 50 Ohms and since the gain requirement is relatively low, it was necessary to increase the negative voltage feedback between collector and base by using a 220 Ohms resistor. In order to establish the proper DC bias condition in the stage, it was necessary to decouple the 3.6 K Ohms bias resistor. The tuned circuit was designed for loaded Q of 2 since its function is phase equalization rather than frequency selectivity. The measured overall gain for the stage was 11 dB and the return loss was better than 24 dB on both input and output.

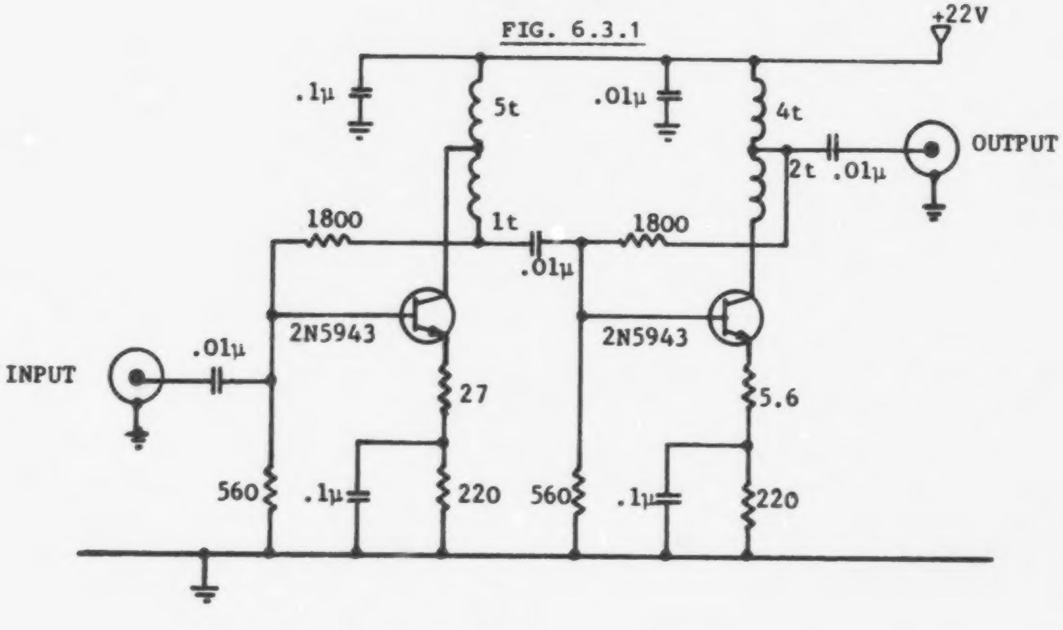
The second IF section requires a gain of 32 dB at 2.2 MHz. The input and output impedance is specified at 50 Ohms. This amplifier was again designed to ensure optimum stability and independance from device tolerance. Negative current and voltage feedback technique was employed. Again, capacitors were used to decouple the DC bias resistors.

The measured gain was 32 dB and the return loss was better than 25 dB on input and output. Figure 6.3.3 shows the circuit diagram.

30 MHz IF AMPLIFIER

GAIN = 32 dB

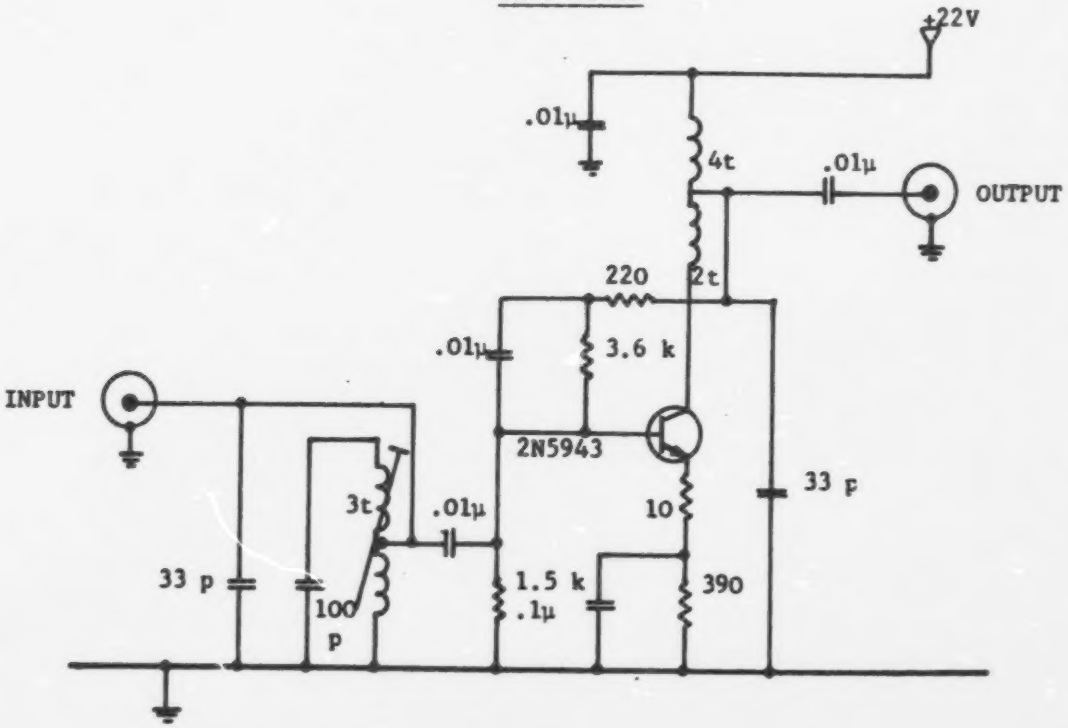
FIG. 6.3.1


+22V
.1µ
5t
.01µ
4t
OUTPUT
2t
.01µ
1800
1t
1800
.01µ
2N5943
2N5943
INPUT
.01µ
27
5.6
560
.1µ
220
560
.1µ
220

30 MHz IF AMPLIFIER

GAIN = 10 dB

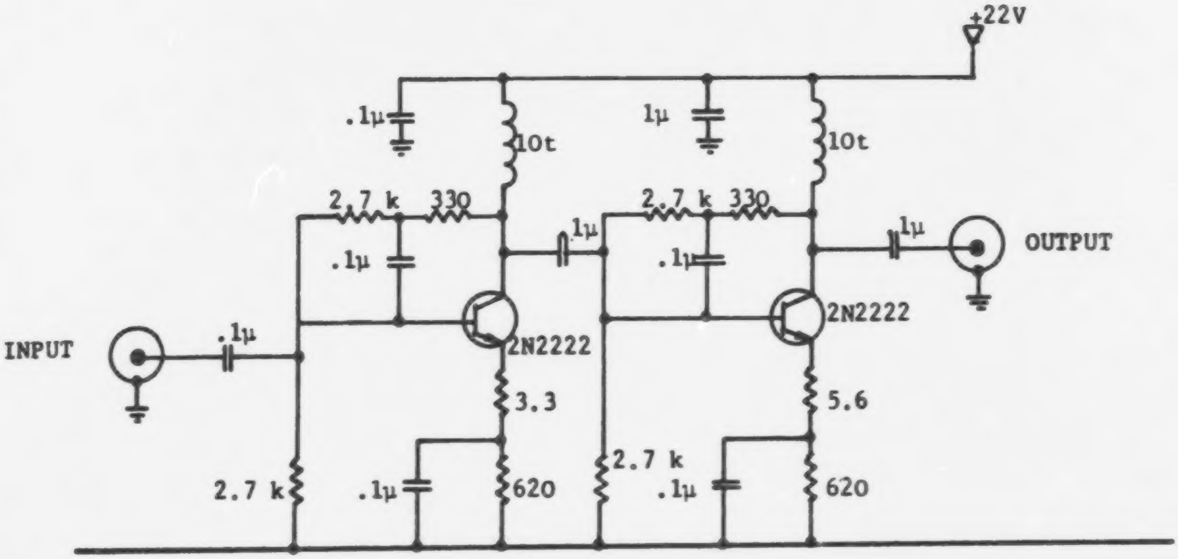
FIG. 6.3.2


+22V
.01µ
4t
.01µ
OUTPUT
220
2t
.01µ
3.6 k
INPUT
2N5943
3t
.01µ
10
33 p
33 p
100 p
1.5 k
.1µ
390

2.2 MHz IF AMPLIEIER

GAIN = 32 dB

FIG. 6.3.3


+22V
.1μ
10t
1μ
10t
2.7 k
330
2.7 k
330
.1μ
.1μ
.1μ
1μ
OUTPUT
INPUT
.1μ
2N2222
2N2222
3.3
5.6
2.7 k
2.7 k
.1μ
620
.1μ
620

6.4 Development of Mixer and Phase Detector (see Fig. 6.4.1)

6.4.1 200 kHz Mixer (see Fig. 6.4.1)

The third intermediate frequency employed in the Doppler Directional Finder was assigned at 200 kHz to provide practical means of obtaining the proper bandwidth and selectivity essential for the operation of the equipment. Conventional double balanced mixers, which are intended for high frequency applications, usually produce increased conversion loss at this lower end of their useful range. Therefore, a decision was made to opt for an active mixer which would lend itself more readily for this application, as well as provide the added advantage of having positive conversion gain. A Dual Gate MOSFET was chosen for this task because of its excellent performance and circuit simplicity.

Two basic methods of local oscillator injection can be used with a MOSFET mixer. One uses gate 1 for both the local oscillator and signal injection, the second uses gate 1 for signal injection with the local oscillator applied to gate 2. When both the signal and local oscillator are injected at gate 1, optimum mixer performance will occur with a particular gate 1 to source bias. However, it is preferable to employ the second method of injection although somewhat higher levels are required for conversion gain comparable to the previous method due to lower gate to drain transconductance of gate 2. This method is more suitable because it is desirable to isolate the local oscillator from both the input and output networks. Therefore, this method of injection was selected for this application. Figure 1 shows the complete mixer circuit. A tuned network was used on the drain to provide initial selectivity while the main bulk of selectivity is obtained from the 200 kHz filter immediately following the mixer. An emitter follower is employed for providing proper impedance transformation as well as some power gain. The overall conversion gain of the stage is 12 dB.

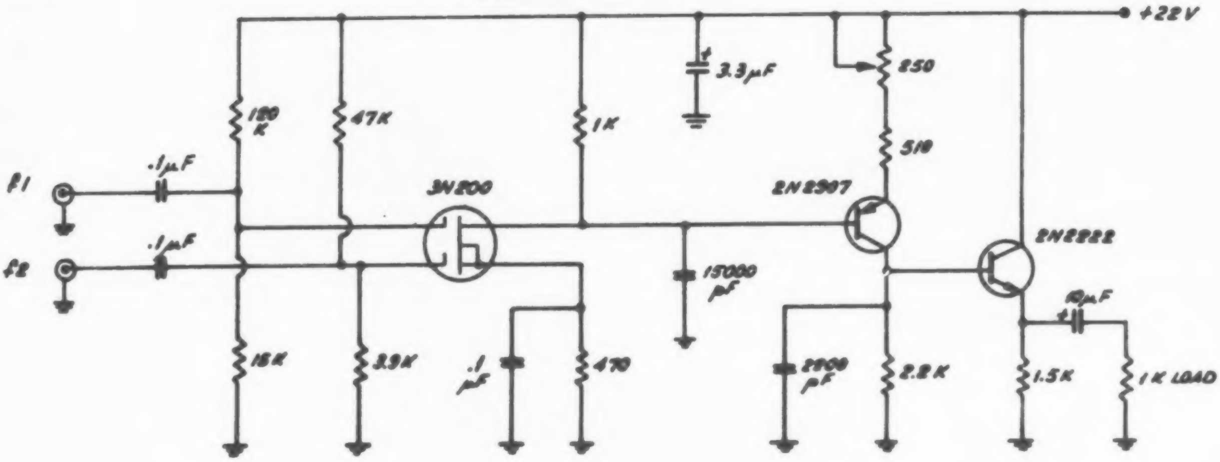
6.4.2 Phase Detector (see Fig. 6.4.2)

The phase detector is the last step in the receiver section of the Doppler Directional Finder whose output is proportional to the relative phase between the two input signals. The basic concept upon which phase detection rests is that the application of two constant amplitude, identical frequency signals to a mixer, results in a DC output which is proportional to the phase difference between the two signals.

While it is true that even a single diode can be used as a phase detector, most involve the use of double balanced mixers for this function.

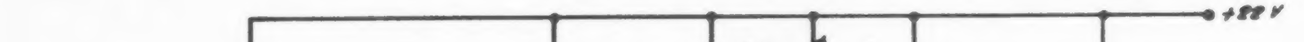
PHASE DETECTOR

FIG. 6.4.1


+22V
3.3μF
250
510
120 K
47K
1K
.1μF
f1
f2
.1μF
3N200
2N2907
2N2222
15000 pF
10μF
15K
3.9K
.1 μF
470
2200 pF
2.2K
1.5K
1K LOAD

200 KHz MIXER

FIG. 6.4.2


+22V
.1μF
1μF
100K
1K
47K
50K
.1μF
1.5K
6300 pF
28.5
.1μF
50
.1μF
2.4 MHz L.O.
3N200
2N2222
G2
G1
2.2 MHz SIGNAL
.1μF
.1μF
200 KHz IF
50
6.8K
.1μF
.1μF
470
680

Due to the reason mentioned previously, it was decided that the same Dual Gate MOSFET mixer should be applied here too, but with the necessary modification. Again, one signal is applied to gate 1 and the other to gate 2. Higher signal level is required for gate 2 as discussed in the foregoing. The output product is injected to a grounded emitter amplifier whose gain is adjustable by the variable emitter resistor. The output from this stage is then used to drive an emitter follower to provide the necessary power gain to drive the load. The maximum voltage swing obtained with this circuit for ±180° change in phase is ±3.5 volts. The schematic is given in Fig. 6.4.2).

The phase detector does not handle continuous signals, the inputs are in the form of short duration pulses corresponding to the sampling periods of the antenna dipoles. Due to the switching arrangement of the antenna, consecutive pulses give alternate phase polarity. For this reason, it is not necessary to provide a DC coupled output from the phase detector. Hence, DC level stability is of no consequence. The AC coupling provided has a time constant sufficient to reproduce the shape of the phase pulses.

6.5 Development of a 200 kHz Compression Amplifier (see Fig. 6.5.1 & 6.5.2)

The dynamic range at the input for the Doppler Directional Finder is specified at 60 dB. This means the receiver should be capable of handling a wide range of input signal levels without any degradation in performance. A common method for achieving such a dynamic range in receivers is by employing an Automatic Gain Control Circuit. This is generally a 'Closed Loop' system which operates by sensing the output level and, by means of the feedback circuit, controls the gain of the preceding stages in order to maintain the outputs at a constant level. Such a system can be designed to operate over a very wide dynamic range. However, because of the action of the feedback, which must incorporate a low pass filter, the overall response time can be relatively long. Therefore, where a faster response is essential, and if the system operation permits, a Limiter Amplifier can be used to control the signal level and maintain the desired output.

A Limiter of Compression Amplifier is basically a conventional amplifier with a limited output threshold. It behaves as a linear amplifier at lower input levels and as a Compression Amplifier at higher levels. The threshold is determined by the device biasing. The circuit usually incorporates a tuned filter to suppress the unwanted spurious and harmonic signals which are inherent in the non-linear operation of the limiter.

The initial proposal for the DF called for the introduction of a 20 dB compression in each of the three intermediate frequency stages in order to distribute the limiting action. However, because of the wider bandwidths involved in the first two IF stages, a decision was made to confine the compression to the last IF where the bandwidth is only 7 kHz.

200 KHz AMPLIFIER LIMITER

GAIN 50 dB MAXIMUM OUTPUT = 6 dBm

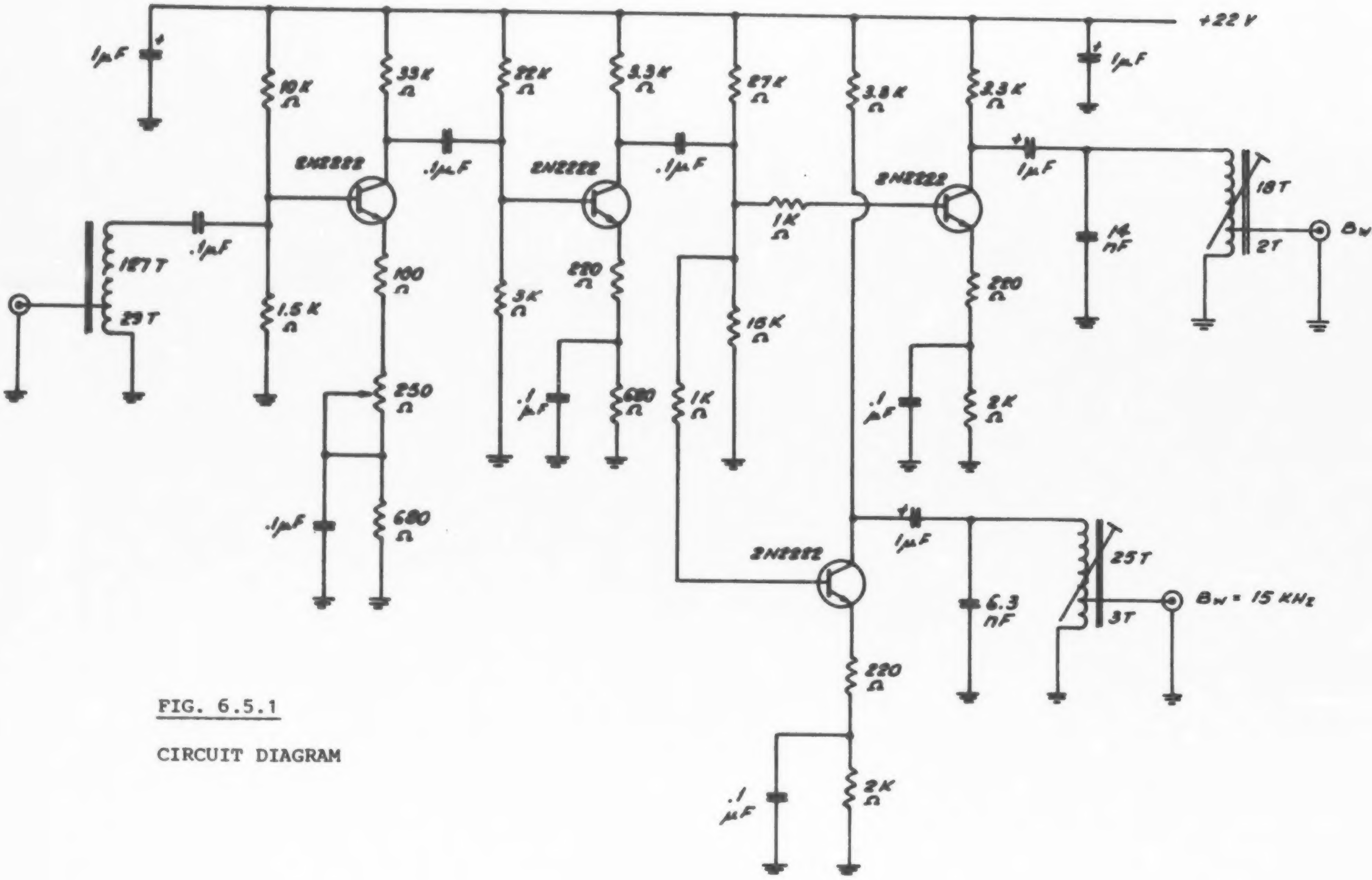

+22 V
1μF
10K Ω
1.5 K Ω
.1μF
187 T
29 T
2N2222
33K Ω
100 Ω
250 Ω
680 Ω
.1μF
.1μF
22K Ω
3K Ω
2N2222
3.3K Ω
220 Ω
680 Ω
.1 μF
.1μF
27K Ω
1K Ω
15K Ω
1K Ω
3.8 K Ω
2N2222
3.3K Ω
220 Ω
2K Ω
.1 μF
1μF
1μF
14 nF
18T
2T
BW=7.5 KHz
2N2222
1μF
6.3 nF
25T
3T
BW = 15 KHz
220 Ω
2K Ω
.1 μF

FIG. 6.5.1

CIRCUIT DIAGRAM

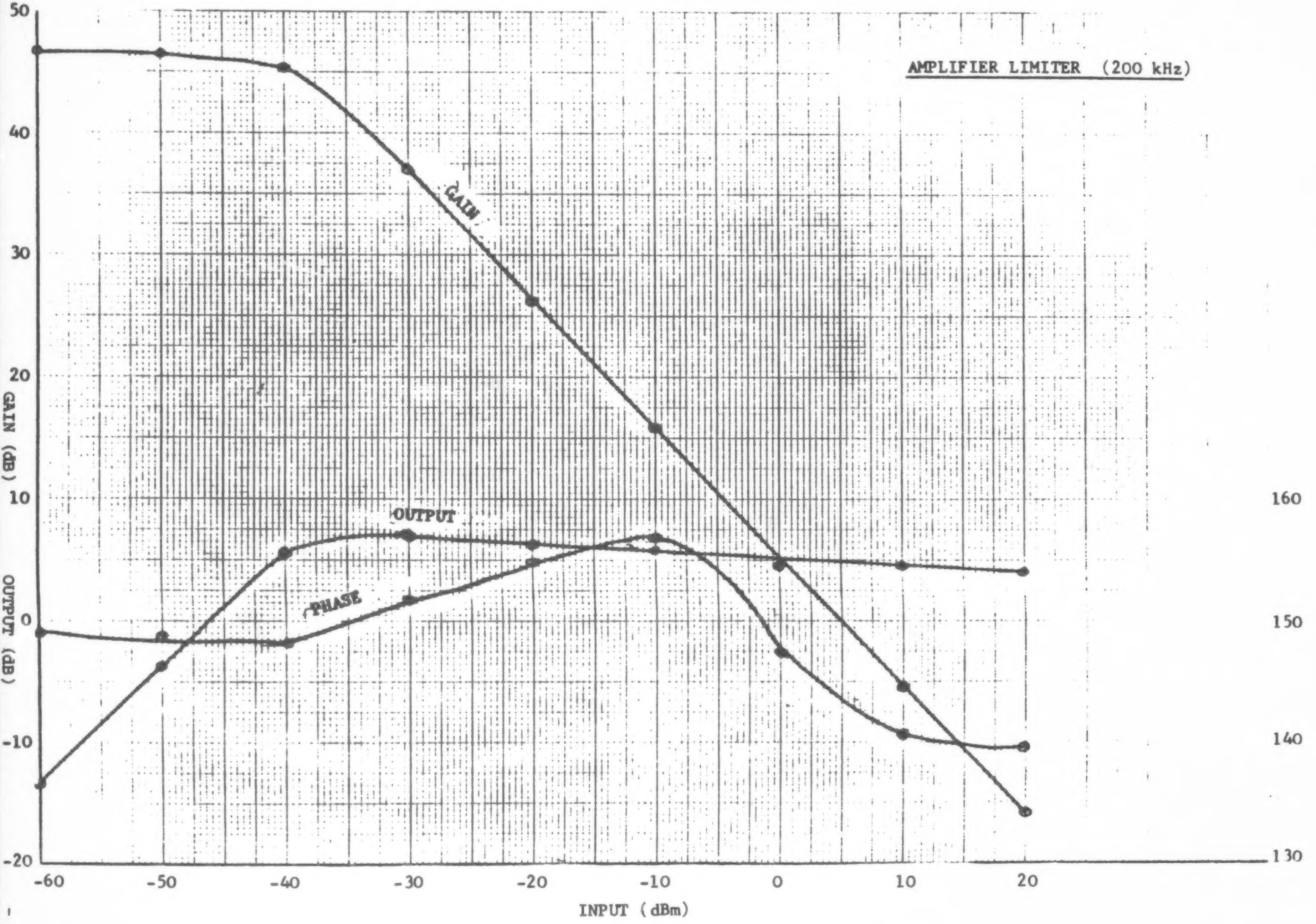


FIG. 6.5.2 - GAIN & PHASE CHARACTERISTICS

This obviously meant that the final IF stage should have the capability of handling over 60 dB of level variation. Also, serious consideration had to be given to the conssitency of phase response versus input level since the accuracy of phase measurement with a twin channel receiver depends on the precision with which the two channels can be matched in phase over the bandwidth and over their full dynamic range.

From the system design, it was determined that this amplifier should have an approximate gain of 50 dB and an output of 0 dBm. The required bandwidth was set at 7 kHz to maximize the signal to noise ratio. However, a 15 kHz bandwidth is necessary to ensure proper operation of the Automatic Frequency Control circuits. In order to satisfy both requirements, the amplifier was designed with two separate outputs.

The attached schematic shows the final amplifier. The first stage incorporates an adjustable resistor in the feedback path to set the overall gain of the amplifier. The phase response is controlled by the alignment of the tuned circuit at the output. Each stage was designed to produce moderate gain (approximately 18 dB), this in addition to the considerable negative current feedback as well as the use of large emitter resistors, good dynamic and thermal stability is assured.

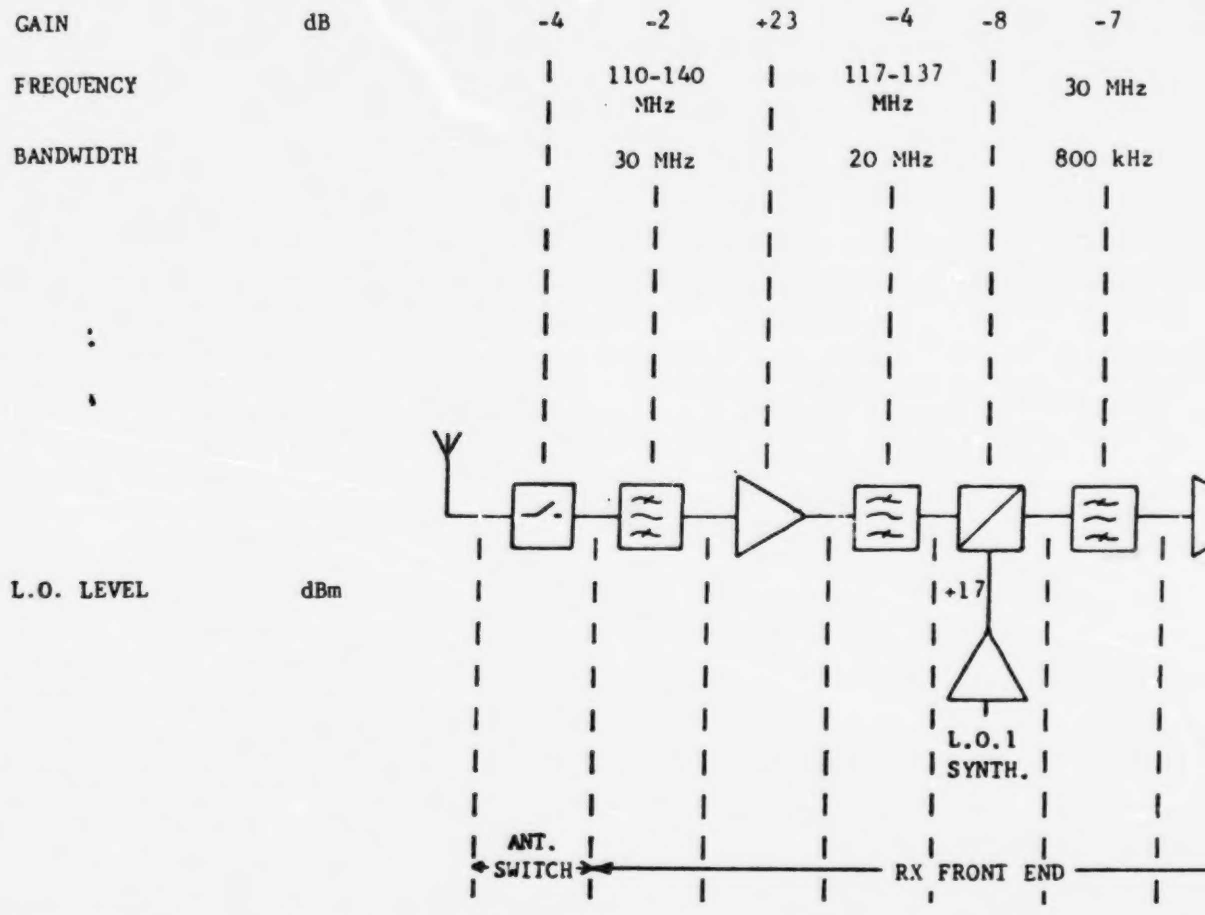
The attached graph shows the gain, phase and output performance versus input signal level. It can be seen that the amplifier behaves linearly up to an input level of -40 dBm, then the gain decreases in a linear relation as level is increased up to 20 dBm. The overall dynamic range is over 80 dB. The total excursion in phase is approximately 16° for the full dynamic range.

In order to prove the consistency and repeatability of the gain and phase performance, two such amplifiers were constructed and tested by injecting a common signal to both via a power divider network and displaying their outputs on an oscilloscope using the Lissajous Figure method. No measurable phase or amplitude difference was detected for the full 80 dB input range.

6.6 DF Twin Channel Receiver Signal and Noise Level Chart

(see Fig. 6.6.1)

Development of the constant phase compression amplifier has led to a change in the design of the DF receiver channels as regards the distribution of signal and noise levels. Phase-independent limiting action could only be achieved at relatively low frequencies and at high signal level. Thus, the entire limiting action was transferred to the last IF stage (200 kHz) where the compression amplifier could be made to handle signals of the order of 1 V.

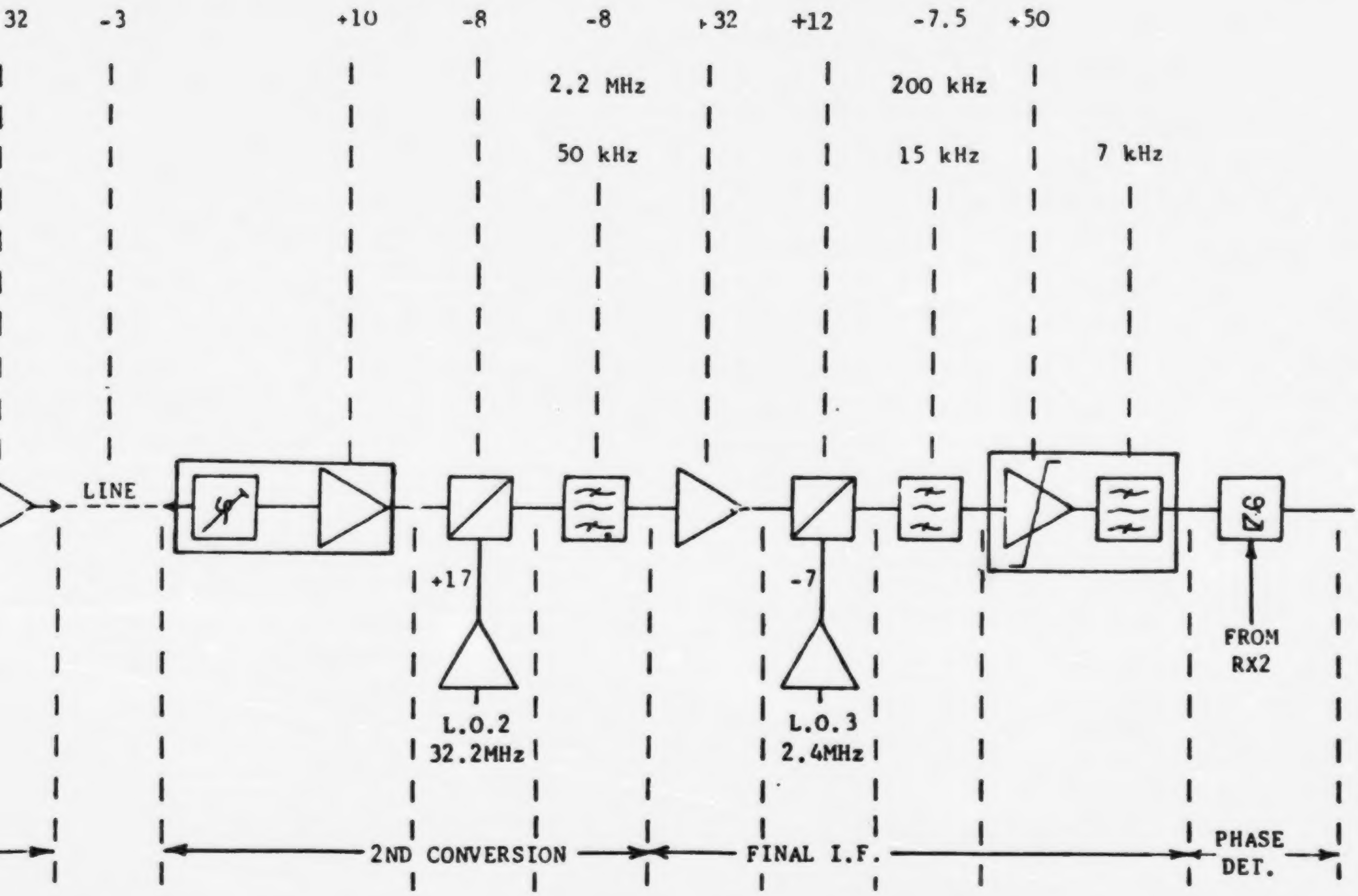

GAIN dB
-4
-2
+23
-4
-8
-7
FREQUENCY
110-140 MHz
117-137 MHz
30 MHz
BANDWIDTH
30 MHz
20 MHz
800 kHz
L.O. LEVEL dBm
+17
L.O.1 SYNTH.
ANT. SWITCH
RX FRONT END

SIGNAL LEVEL	µV min	1.22	0.77	1.22	14.14	4.46	1.77	1.58
	dBm max	-107	-111	-113	-90	-94	-102	-109
	dBm max	-47	-51	-53	-30	-34	-42	-49
NOISE LEVEL AT BW	dBm			-93.17	-70.17	-75.93	-83.93	-106.67
S/N RATIO AT MIN SIGNAL	dB			-19.83	-19.83			
IMPEDANCE LEVEL		75	75	300	200	50	50	200

FIG. 6.6.1

DOPPLER DF TWIN CHANNEL RECEIVER

SIGNAL & NOISE LEVEL CHART


32
-3
+10
-8
-8
+32
+12
-7.5
+50
2.2 MHz
50 kHz
200 kHz
15 kHz
7 kHz
LINE
+17
L.O.2
32.2MHz
-7
L.O.3
2.4MHz
∠θ
FROM
RX2
2ND CONVERSION
FINAL I.F.
PHASE
DET.

31.58	22.36	70.71	28.15	11.2	446.1	1776	749	.23V
-77	-80	-70	-78	-86	-54	-42	-49.5	+.5
-17	-20	-10	-18	-26	+6	+2	-5.5	+6
-74.67	-77.67	-67.67	-75.67	-95.71	-63.71	-51.71	-64.44	-177 5
-2.33		-2.33		9.71	9.71		14.94	18.25
50	50	50	50	50	50	50	50	50

To reflect this change, a new signal and noise chart has been drawn up (see Progress Report No. 7, Appendix 1) showing minimum and maximum signal levels and the signal to noise ratios related to the bandwidth of each stage. This chart is not a design target. It represents performance achieved on circuit blocks already developed for incorporation in the receiver. To avoid intermodulation, the signal level is kept low right up to the third conversion allowing only sufficient gain to maintain a gradual increase of the signal to noise ratio. The third mixer was re-designed to handle the increased signal level. Worth noting is the reduction of final IF bandwidth to 7 kHz as applied to the phase detector, giving a further improvement in noise selectivity. This was made possible by providing a separate wide band (15 kHz) output to drive the AFC which is expected to take care of the transmitter frequency drift (compare schematic of Appendix 1 of Progress Report No. 7).

6.7 Antenna Unit and Receiver Block Diagrams (see Fig. 6.7.1)

To summarize the design concept of the antenna and receiver subsystems, a set of block diagrams have been drawn up to show the signal flow and processing along for the four separate functions of the equipment:

1) The DF Doppler antenna array and twin-channel receiver

2) The audio receiver channel, and

3) The emergency receiver channel - the latter two having a combined r.f. pre-amplifier connected to the omnidirectional antenna.

4) The test injection facility for instant testing of the complete system.

The diagrams are enclosed on the following pages.

6.8 Frequency Synthesizer

6.8.1 Design Philosophy

The synthesizer circuit shown is of conventional design for this frequency range. There initially appears to be an added complication of a crystal controlled downmix system before the variable divider. This also seems complicated by the fact that three crystal frequencies are used. The reason for this is that it is necessary to keep the loop gain from varying over a wide range and keeping it fairly high. Dividing the VHF signal directly down to 25 kHz would require a high division ratio. The error frequency (or deviation from the required output frequency) would be divided by an equivalent amount. The error pulses from the phase comparator would be very short for a large error frequency, as compared with a system of translating the error frequency to a lower frequency before division. Very narrow error pulses are difficult to integrate with sufficiently low noise.

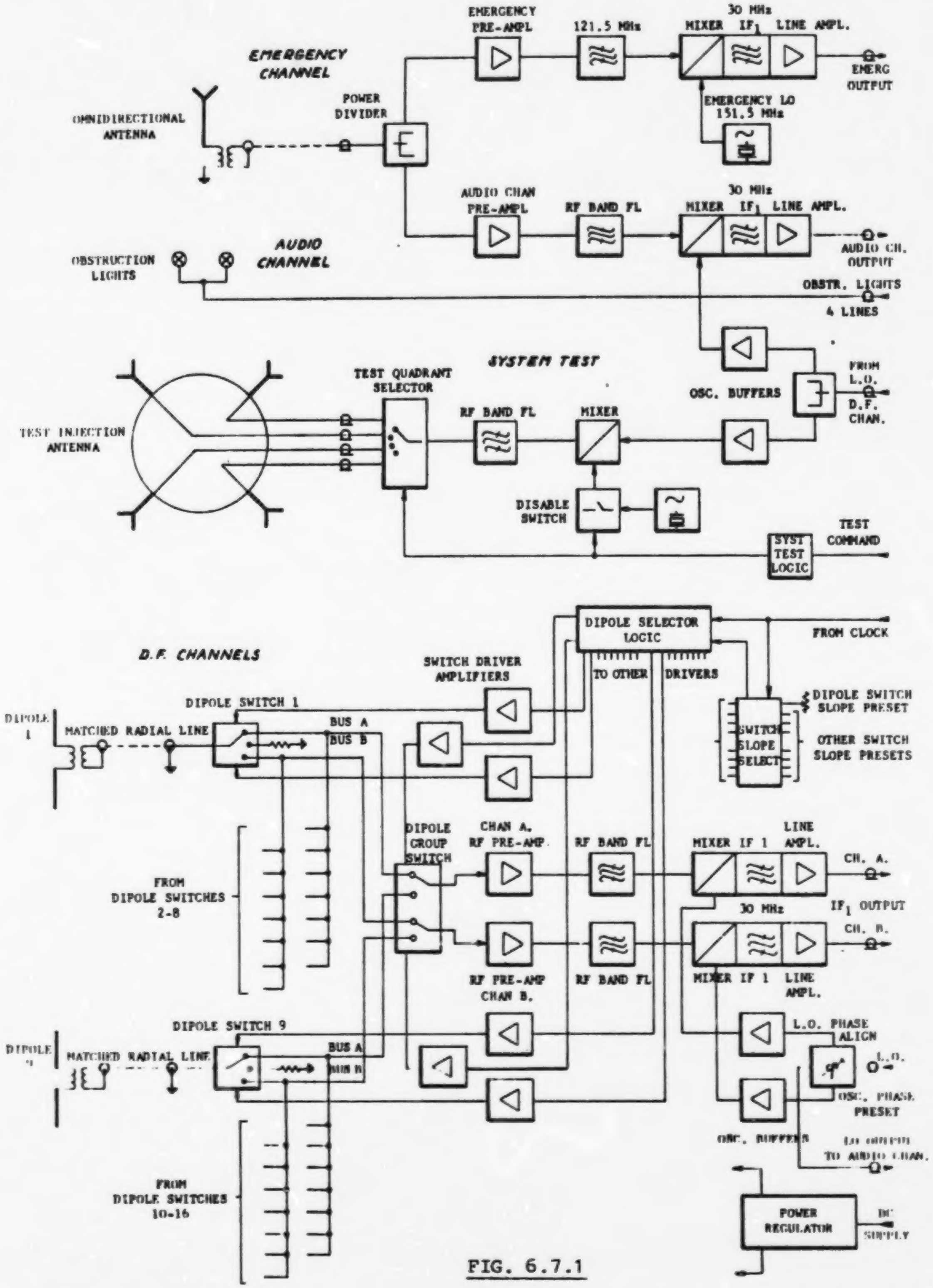

EMERGENCY CHANNEL
OMNIDIRECTIONAL ANTENNA
POWER DIVIDER
EMERGENCY PRE-AMPL
121.5 MHz
30 MHz
MIXER IF$_1$ LINE AMPL.
EMERG OUTPUT
EMERGENCY LO 151.5 MHz
AUDIO CHAN PRE-AMPL
RF BAND FL
30 MHz
MIXER IF$_1$ LINE AMPL.
AUDIO CH. OUTPUT
AUDIO CHANNEL
OBSTRUCTION LIGHTS
OBSTR. LIGHTS
4 LINES
SYSTEM TEST
TEST QUADRANT SELECTOR
TEST INJECTION ANTENNA
RF BAND FL
MIXER
OSC. BUFFERS
FROM L.O. D.F. CHAN.
DISABLE SWITCH
SYST TEST LOGIC
TEST COMMAND
D.F. CHANNELS
DIPOLE SELECTOR LOGIC
FROM CLOCK
SWITCH DRIVER AMPLIFIERS
TO OTHER DRIVERS
DIPOLE SWITCH SLOPE PRESET
SWITCH SLOPE SELECT
OTHER SWITCH SLOPE PRESETS
DIPOLE SWITCH 1
DIPOLE 1
MATCHED RADIAL LINE
BUS A
BUS B
FROM DIPOLE SWITCHES 2-8
DIPOLE GROUP SWITCH
CHAN A. RF PRE-AMP.
RF BAND FL
MIXER IF 1
LINE AMPL.
CH. A.
30 MHz
IF$_1$ OUTPUT
CH. B.
RF PRE-AMP CHAN B.
RF BAND FL
MIXER IF 1
LINE AMPL.
DIPOLE SWITCH 9
DIPOLE 9
MATCHED RADIAL LINE
BUS A
BUS B
L.O. PHASE ALIGN
L.O.
OSC. PHASE PRESET
OSC. BUFFERS
LO OUTPUT TO AUDIO CHAN.
FROM DIPOLE SWITCHES 10-16
POWER REGULATOR
DC SUPPLY

FIG. 6.7.1

DOPPLER RADIO DF

ANTENNA UNIT BLOCK DIAGRAM

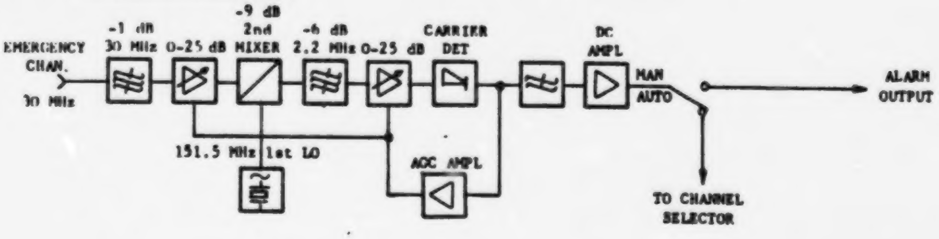
(16 DIPOLE ARRAY)

D.F. RECEIVER BLOCK DIAGRAM

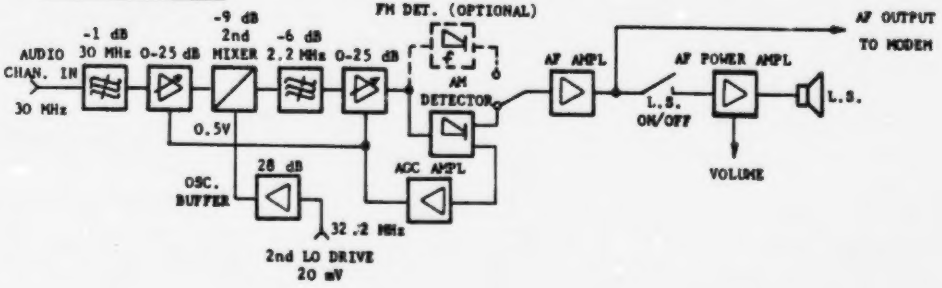
(RECEIVER UNIT)

FIG. 6.7.2

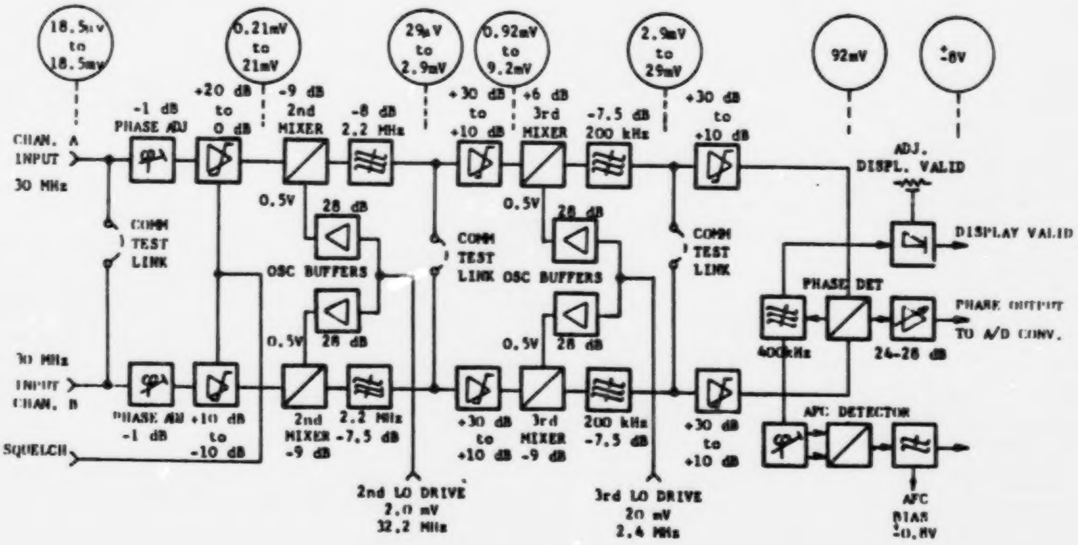
EMERGENCY CHANNEL


EMERGENCY CHAN.
30 MHz
-1 dB
30 MHz
0-25 dB
-9 dB
2nd MIXER
-6 dB
2.2 MHz
0-25 dB
CARRIER DET
DC AMPL
MAN
AUTO
ALARM OUTPUT
151.5 MHz 1st LO
AGC AMPL
TO CHANNEL SELECTOR

AUDIO CHANNEL


AUDIO CHAN. IN
30 MHz
-1 dB
30 MHz
0-25 dB
-9 dB
2nd MIXER
-6 dB
2.2 MHz
0-25 dB
FM DET. (OPTIONAL)
AM DETECTOR
AF AMPL
AF OUTPUT TO MODEM
AF POWER AMPL
L.S. ON/OFF
L.S.
VOLUME
0.5V
28 dB
OSC. BUFFER
AGC AMPL
32.2 MHz
2nd LO DRIVE
20 mV

D.F CHANNELS


18.5uv to 18.5mv
0.21mV to 21mV
29uV to 2.9mV
0.92mV to 9.2mV
2.9mV to 29mV
92mV
±8V
CHAN. A INPUT
30 MHz
-1 dB
PHASE ADJ
+20 dB to 0 dB
-9 dB
2nd MIXER
-8 dB
2.2 MHz
+30 dB to +10 dB
+6 dB
3rd MIXER
-7.5 dB
200 kHz
+30 dB to +10 dB
ADJ. DISPL. VALID
DISPLAY VALID
COMM TEST LINK
0.5V
28 dB
OSC BUFFERS
COMM TEST LINK
0.5V
28 dB
OSC BUFFERS
COMM TEST LINK
PHASE DET
PHASE OUTPUT TO A/D CONV.
400kHz
24-28 dB
0.5V
28 dB
0.5V
28 dB
30 MHz
INPUT CHAN. B
PHASE ADJ
-1 dB
+10 dB to -10 dB
2nd MIXER -9 dB
2.2 MHz -7.5 dB
+30 dB to +10 dB
3rd MIXER -9 dB
200 kHz -7.5 dB
+30 dB to +10 dB
AFC DETECTOR
SQUELCH
2nd LO DRIVE
2.0 mV
32.2 MHz
3rd LO DRIVE
20 mV
2.4 MHz
AFC BIAS
±0.8V

With the frequency range required, the translation process produces a division ratio which varies by a factor of 3 to 1. This means the loop gain varies by this same factor. With such a large variation, problems of loop instability and lack of loop gain will appear at each end of the frequency range. The variation is reduced in this design by confining the downmixed frequency to a narrow range by changing the crystal oscillator frequency.

6.8.2 Breakdown of Development Tasks

6.8.2.1 Develop VCO Circuit

This is one of the more difficult sections of the synthesizer. The selectivity of the radio is, in part, dependent upon the purity of the output with regard to noise close to the carrier. To develop a 'quiet' VCO, a high Q tuned circuit, lightly loaded by the rest of the circuit, is required. The other problem is susceptibility to mechanical vibration. It is necessary to produce a mechanically rigid structure to minimize this. Note that the VCO section is split into three sections. This is to reduce the required frequency range of each VCO, enabling optimization over each band to be made.

6.8.2.2 Develop Loop Amplifier

This also requires a great level of care in development. The effectiveness of the loop amplifier in producing a pure DC output proportional to the pulse width of the pulses from the phase detector, has a significant effect on the purity of the output signal. Noise or fluctuations of even a very low order are superimposed as FM products on the VCO, and degrade the selectivity.

6.8.2.3 Crystal Oscillator and Mixer

These sections are of fairly straightforward design. The crystal oscillator is a fifth overtone type, and requires only a small frequency deviation control input for AFC. The mixer and the low pass filter also do not present much difficulty since the low frequency output signal can be easily filtered from the two VHF signals.

6.8.2.4 Variable Divider and Phase Comparator

These can be easily designed using conventional low power Schottky logic counters. The phase comparator is also a standard part, but requires some careful output biasing to remove 'dead zone' problems inherent in this component. This module will require extensive screening and buffering to prevent the many frequencies generated from interfering with the receive frequency.

6.8.2.5 Reference Oscillator and Divider

The reference oscillator is derived from the second local oscillator in the receiver. The input will require some buffering to prevent radiation of synthesizer spurious frequencies into the later stages of the receiver. The divider, which provides the 25 kHz reference frequency, consists of two standard integrated circuits.

6.8.3 Specifications

Receiver Input Frequency	:	117.5 MHz-136.5 (ATC) immediate requirement, or 156-174 (Marine) for later adaptation
1st IF	:	32.1 MHz (to be confirmed regarding filter)
Synthesizer Output	:	149.6 - 168.6 MHz (ATC) 187.1 - 206.1 MHz (Marine)
Channel Spacing	:	25 kHz
Frequency Stability	:	25 ppm minimum over temperature range of -50°C to +55°C

Temperature control oven may be used, providing warm up time does not appreciably increase down time.

Channel Selection	:	6 or 12 channels - each channel frequency programmable within the equipment
Channel Select Reporting	:	Back from remote to light a lamp in the channel select pushbutton.
Manual Channel Selection	:	From the remote unit when in Remote position
AFC	:	Pull in range of ±7.5 kHz
AFC Signal	;	400 kHz from the phase detector (module frequency)
Acquisition Time	:	100 ms
Output Level	:	30 - 50 mV into 50Ω preset to give 30 mV at the antenna unit

Spurious Output : 85 dB or better within ±20 kHz

Filter Noise : 40 dB at ±1.5 kHz bandwidth

Failure Indicator : LED on the front panel

Power Supply : ±15 V and +5 V

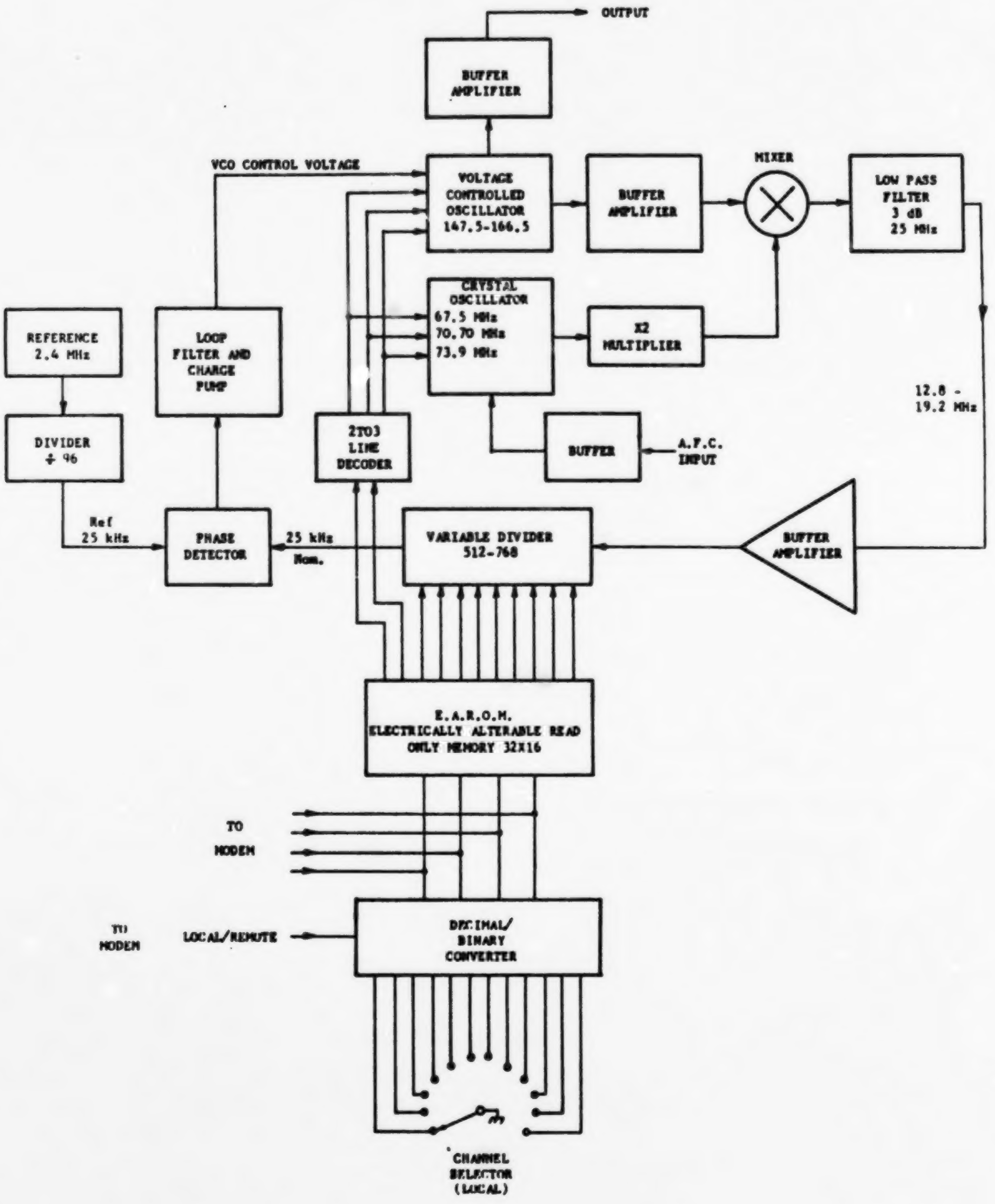
General Specification : DTA 1000

Master Oscillator : 2400 kHz preferred (common with 2nd LO of the twin channel receiver)

Master Oscillator Auxiliary Output : 0.1 V into 50Ω for driving buffer amplifiers in the receiver

FIG. 6.8.1

FREQUENCY SYNTHESIZER - BLOCK DIAGRAM


OUTPUT
BUFFER AMPLIFIER
VCO CONTROL VOLTAGE
VOLTAGE CONTROLLED OSCILLATOR 147.5-166.5
BUFFER AMPLIFIER
MIXER
LOW PASS FILTER 3 dB 25 MHz
CRYSTAL OSCILLATOR
67.5 MHz
70.70 MHz
73.9 MHz
X2 MULTIPLIER
REFERENCE 2.4 MHz
LOOP FILTER AND CHARGE PUMP
12.8 - 19.2 MHz
DIVIDER ÷ 96
2TO3 LINE DECODER
BUFFER
A.F.C. INPUT
Ref 25 kHz
PHASE DETECTOR
25 kHz Nom.
VARIABLE DIVIDER 512-768
BUFFER AMPLIFIER
E.A.R.O.M. ELECTRICALLY ALTERABLE READ ONLY MEMORY 32X16
TO MODEM
TO MODEM
LOCAL/REMOTE
DECIMAL/ BINARY CONVERTER
CHANNEL SELECTOR (LOCAL)

6.9 Bearing Processor

This sub-system receives the phase difference signal from the receiver phase comparator and produces 3½ digit BCD bearing angle reading. It also produces a single output indicating 'plane overhead' situation.

The processor is shown in the block diagram of Fig. 6.9.1 and each module is described as follows:

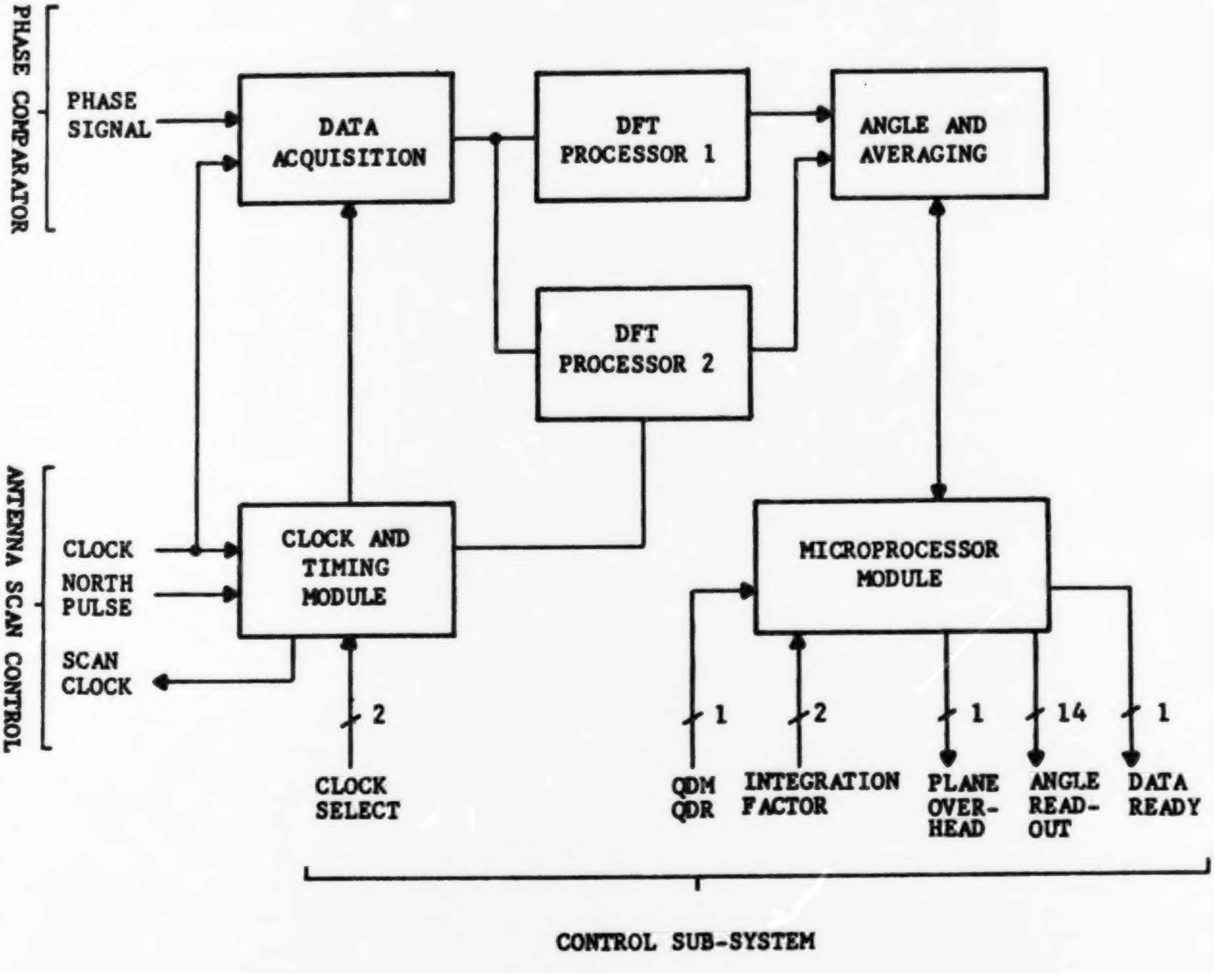

PHASE COMPARATOR
PHASE SIGNAL
DATA ACQUISITION
DFT PROCESSOR 1
ANGLE AND AVERAGING
DFT PROCESSOR 2
ANTENNA SCAN CONTROL
CLOCK
NORTH PULSE
SCAN CLOCK
CLOCK AND TIMING MODULE
MICROPROCESSOR MODULE
2
1
2
1
14
1
CLOCK SELECT
QDM QDR
INTEGRATION FACTOR
PLANE OVER-HEAD
ANGLE READ-OUT
DATA READY
CONTROL SUB-SYSTEM

FIG. 6.9.1 - BEARING PROCESSOR BLOCK DIAGRAM

6.9.1 Data Acquisition Module

This module samples the phase angle signal and converts it to digital for further digital processing.

The phase angle of a selected dipole pair is represented by the amplitude of a pulse termed video pulse, output by the phase comparator. Noise on this pulse makes it very difficult to do direct measurement of the amplitude. Integration of the pulse, over a known time window, is in turn measured by the sampler. This method gives an excellent averaged measure of the amplitude, therefore, it is fed to Analog to Digital converter.

Fig. 6.9.2 gives the block diagram of this module and Fig. 6.9.3 shows the associated timing.

The window pulse is generated from antenna switch scan clock with the proper delay to compensate for the receiver delay.

6.9.2 DFT Processors

The digitized phase signal is multiplied by SIN and COS of the angle of present dipole from North. These multiplications are accumulated over a complete rotation and the results are given to Angle and Averaging module as Real and Imaginary parts of the fundamental. This is according to the discrete fourier transformation of sampled signals, i.e.

$$\begin{aligned} \mathrm{Re}\ (F) &= \sum_{n=0}^{N-1} F_n \cdot \ \mathrm{COS}\left(\frac{2\pi n}{N}\right) \\ \mathrm{Im}\ (F) &= \sum_{n=0}^{N-1} F_n \cdot \ \mathrm{SIN}\left(\frac{2\pi n}{N}\right) \end{aligned} \qquad (1)$$

where Fn is samples and Re and Im are real and imaginary parts of fundamental

The bearing angle is given by:

$$\theta = \tan^{-1} \frac{\mathrm{Im}\ (F)}{\mathrm{Re}\ (F)} \qquad (2)$$

Also, plane overhead signal is generated by comparing the fundamental amplitude /F/ to some value which is a function of viewing angle, and:

$$/F/ = \sqrt{\mathrm{Re}^2(F) + \mathrm{Im}^2(F)} \qquad (3)$$

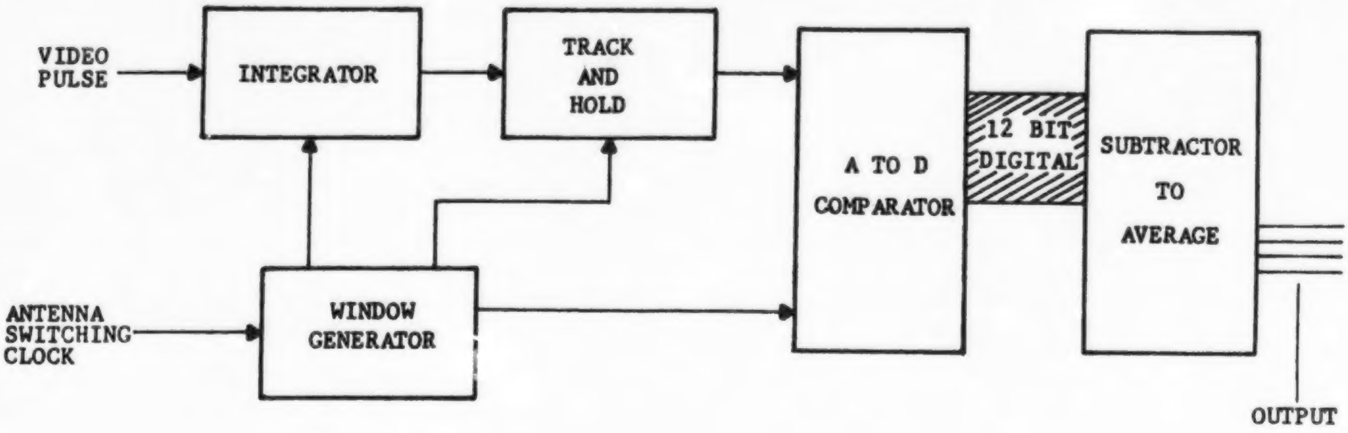

VIDEO PULSE
INTEGRATOR
TRACK AND HOLD
A TO D COMPARATOR
12 BIT DIGITAL
SUBTRACTOR TO AVERAGE
ANTENNA SWITCHING CLOCK
WINDOW GENERATOR
OUTPUT

FIG. 6.9.2 - BLOCK DIAGRAM OF DATA ACQUISITION

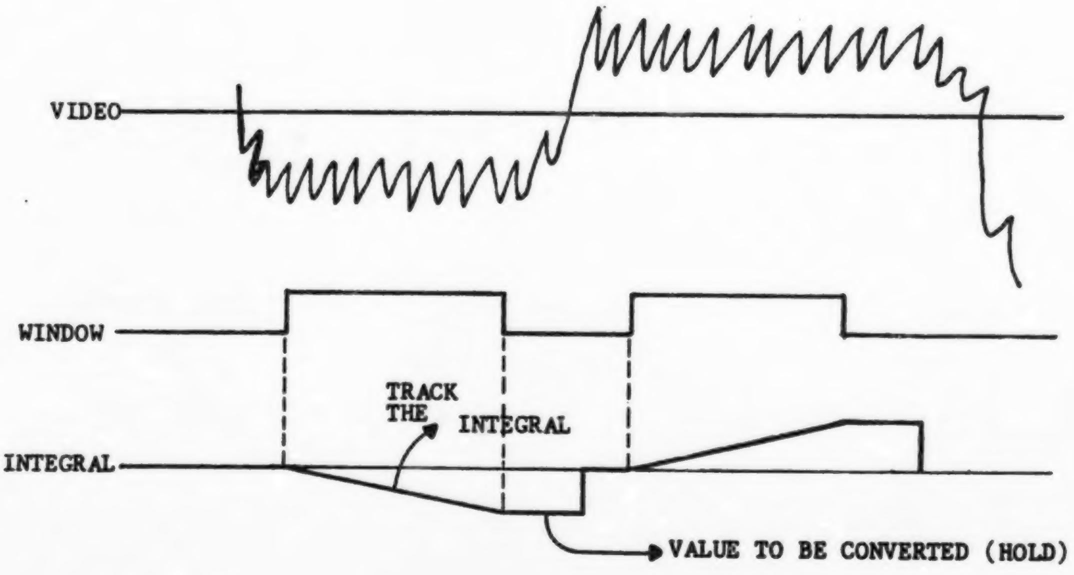

VIDEO
WINDOW
TRACK THE INTEGRAL
INTEGRAL
VALUE TO BE CONVERTED (HOLD)

FIG. 6.9.3 - DATA ACQUISITION TIMING

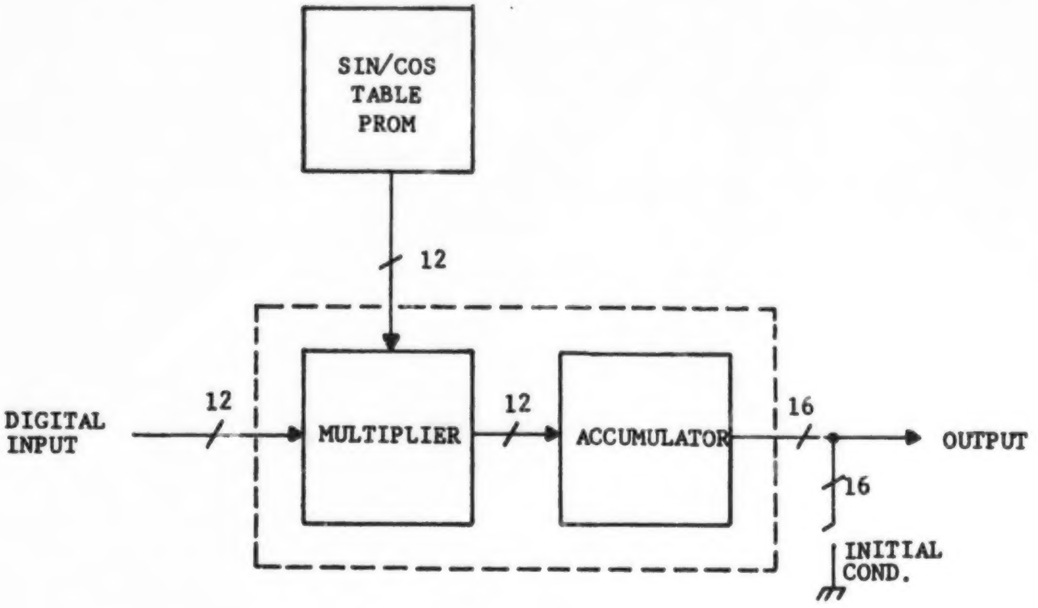

SIN/COS
TABLE
PROM
12
DIGITAL INPUT
12
MULTIPLIER
12
ACCUMULATOR
16
OUTPUT
16
INITIAL COND.

FIG. 6.9.4 - DFT PROCESSOR MODULE

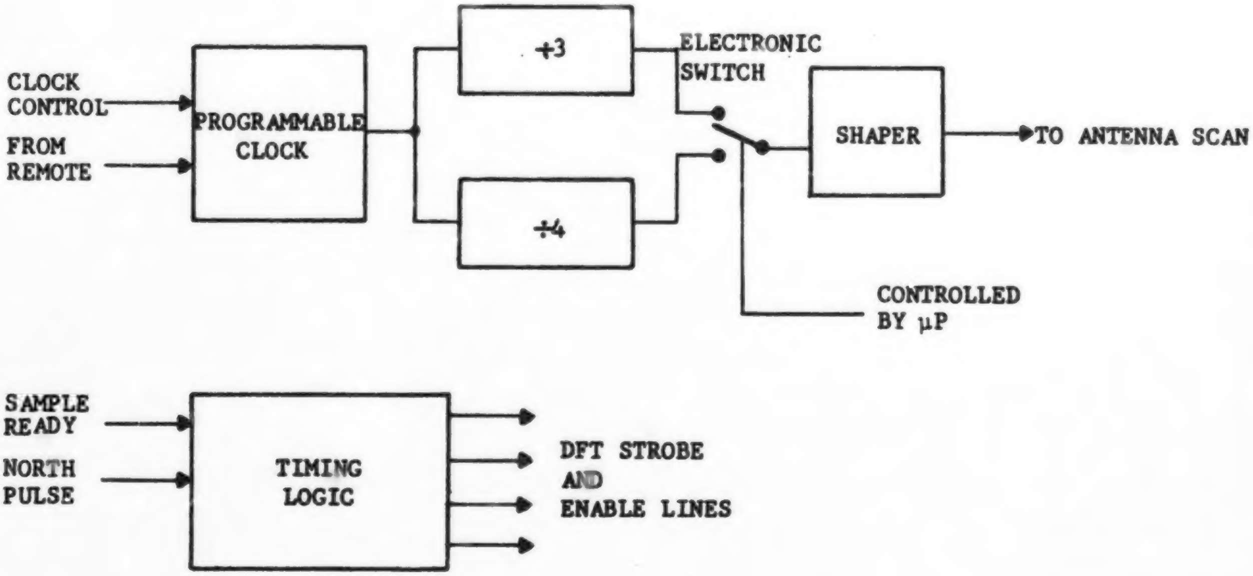

CLOCK CONTROL
FROM REMOTE
PROGRAMMABLE CLOCK
÷3
÷4
ELECTRONIC SWITCH
SHAPER
TO ANTENNA SCAN
CONTROLLED BY μP
SAMPLE READY
NORTH PULSE
TIMING LOGIC
DFT STROBE AND ENABLE LINES

FIG. 6.9.5 - CLOCK OF TIMING MODULE

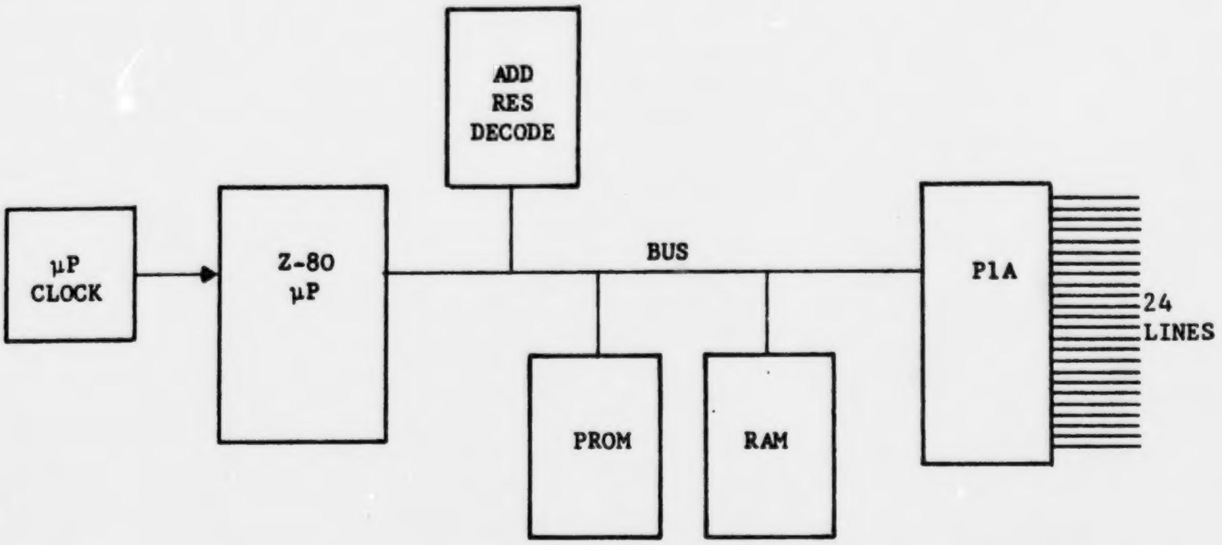

ADD
RES
DECODE
µP
CLOCK
Z-80
µP
BUS
P1A
24
LINES
PROM
RAM

FIG. 6.9.6 - MICROPROCESSOR MODULE

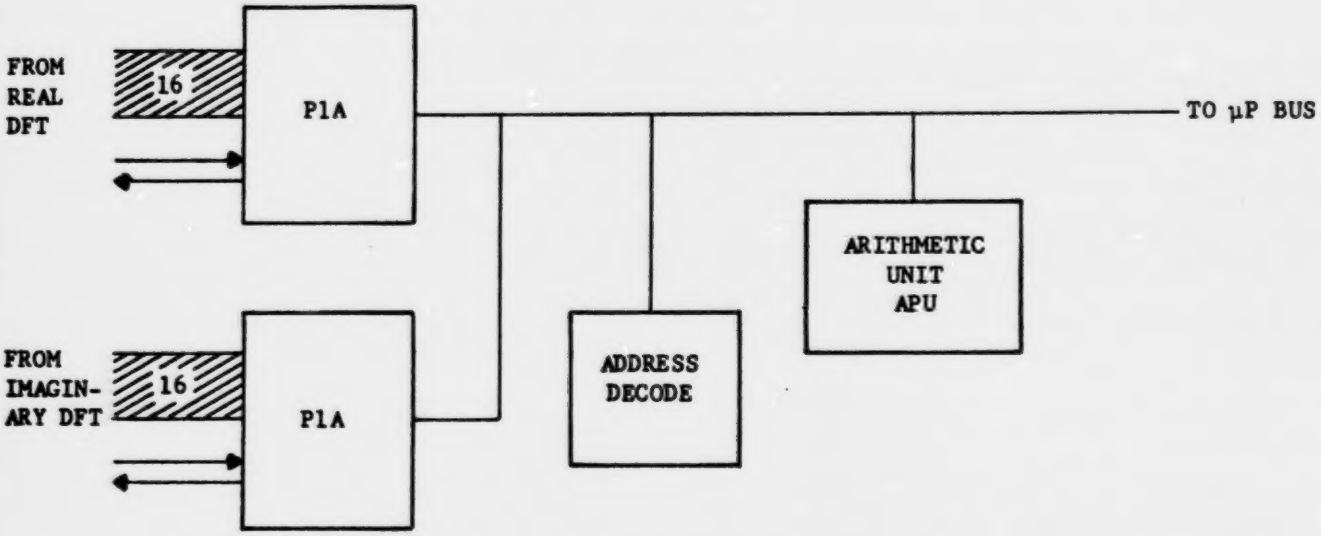

FROM
REAL
DFT
16
P1A
TO µP BUS
ARITHMETIC
UNIT
APU
FROM
IMAGIN-
ARY DFT
16
P1A
ADDRESS
DECODE

FIG. 6.9.7 - ANGLE AND AVERAGING UNIT

(2) and (3) are calculated in microprocessor and angle module.

DFT1 and DF2 are similar except one contains SIn table so it calculated Im(F) and the other contains COS table to calculate Re(F).

Fig. 6.9.4 shows the block diagram of each processor.

6.9.3 Clock and Timing Module

This module contains the master clock for the sub-system in addition to the timing circuit to control the flow of data in other modules.

The clock is a programmable oscillator which provides remote control change of the frequency by ±8%. The output is fed to ÷ 3 and ÷ 4 counters which is selected by a switch controlled by microprocessor module, Fig. 6.9.5.

The timing circuit is a digital circuitry generating the strobe and enable pulses required by processors.

6.9.4 Microprocessor Module

This module contains a Z-80 microprocessor, clock, up to 4K PROM, 1K RAM, 24 line parallelled interface, and the address decoding for the above.

Functions like averaging, division, are tan table look-up and statistic to obtain the best averaging are performed by the software stored in the PROM.

The parallelled interface port is the remote control sub-system. It contains 14 lines for angle readout, 1 line data ready, 1 line plane overhead, and 1 line for scan frequency select. Also, it contains the input lines such as QDM/QDR, integration constant from remote, etc.

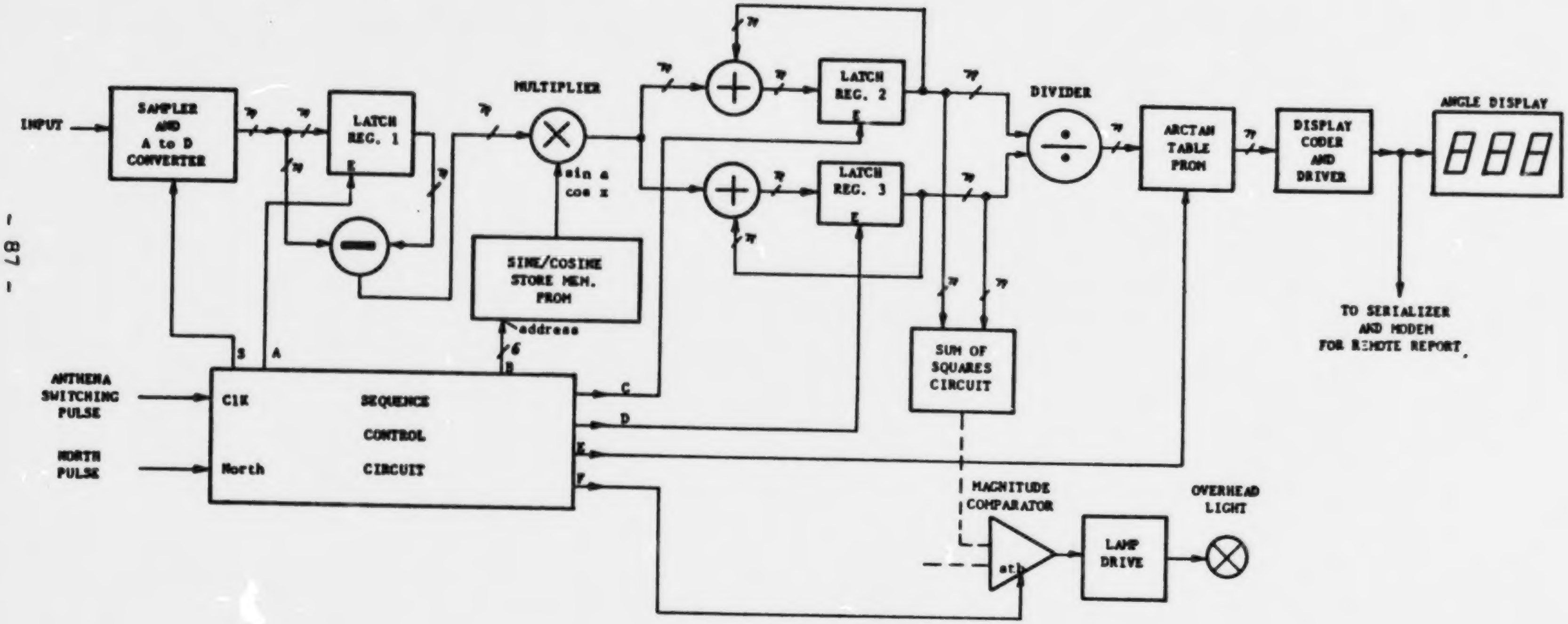
The module is block diagrammed in Fig. 6.9.6.

6.9.5 Angle and Averaging Module

This module receives the Re and Im parts of fundamental as described in DFT module and forwards this to microprocessor module for software processing. It also contains a hardware arithmetic processor to help the microprocessor when a fast arithmetic calculation is needed such as division, squaring and square rooting.

6.9.6 Summary of Bearing Processor Concept

The combined operation of the bearing processor functions is summarized in the overall bearing processor block diagram of Fig. 6.9.8. The complete processing sequence is explained in the algorithm flow graph of Fig. 6.9.9.


INPUT
SAMPLER AND A to D CONVERTER
LATCH REG. 1
MULTIPLIER
sin x
cos x
SINE/COSINE STORE MEM. PROM
address
6
LATCH REG. 2
LATCH REG. 3
E
DIVIDER
ARCTAN TABLE PROM
DISPLAY CODER AND DRIVER
ANGLE DISPLAY
888
TO SERIALIZER AND MODEM FOR REMOTE REPORT
SUM OF SQUARES CIRCUIT
MAGNITUDE COMPARATOR
sth
LAMP DRIVE
OVERHEAD LIGHT
ANTENNA SWITCHING PULSE
NORTH PULSE
S
A
B
C
D
E
F
C1K
North
SEQUENCE CONTROL CIRCUIT

DOPPLER DF - BEARING DATA PROCESSOR

BLOCK DIAGRAM

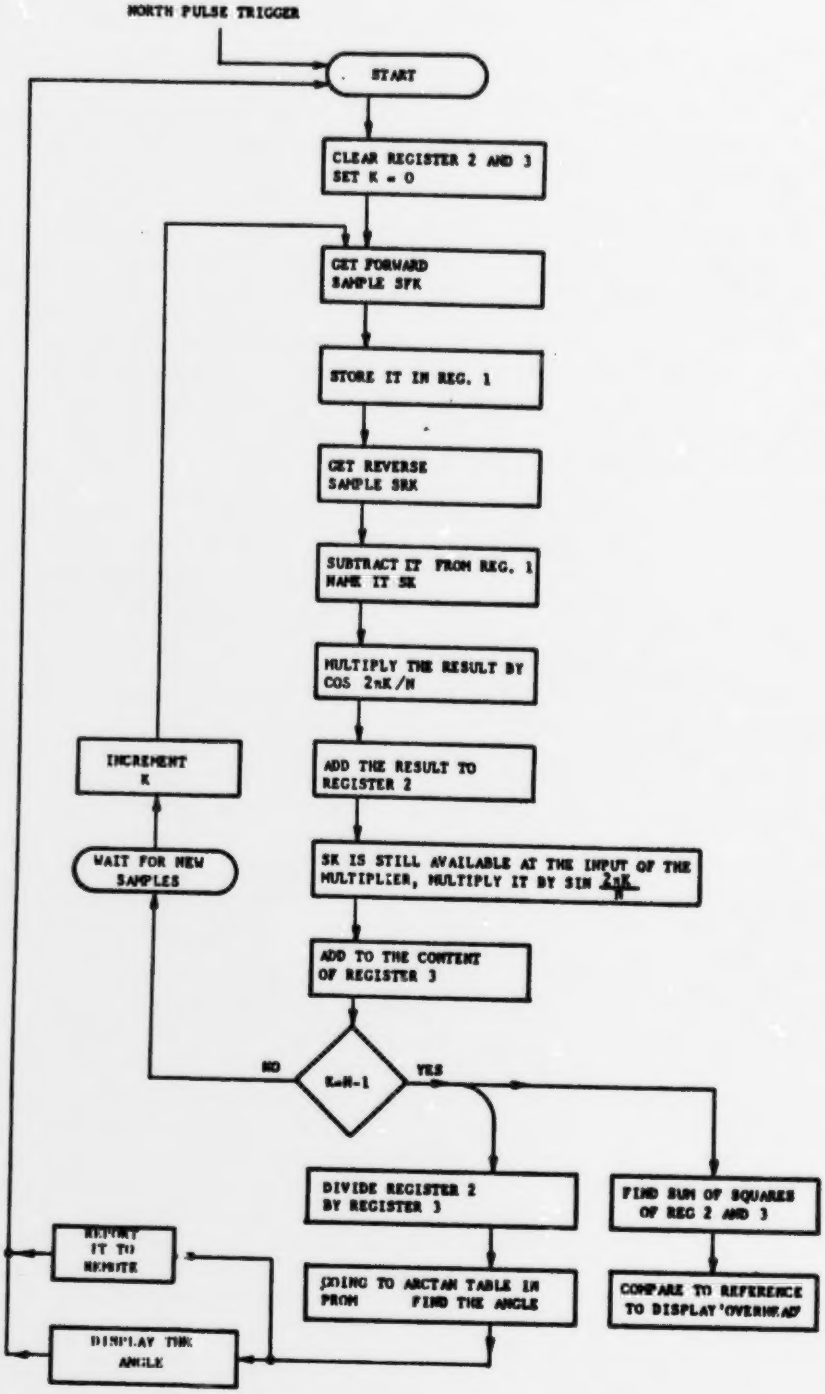
FIG. 6.9.8

FIG. 6.9.9 - ALGORITHM FLOW GRAPH

USE:

$$\mathrm{Re}\ X(1) = \sum_{K=0}^{N-1} X(K) \cos \frac{2\pi K}{N} \qquad \text{where } N = 32$$

$$\mathrm{Im}\ X(1) = \sum_{K=0}^{N-1} X(K) \sin \frac{2\pi K}{N}$$


NORTH PULSE TRIGGER
START
CLEAR REGISTER 2 AND 3
SET K = 0
GET FORWARD
SAMPLE SFK
STORE IT IN REG. 1
GET REVERSE
SAMPLE SRK
SUBTRACT IT FROM REG. 1
NAME IT SK
MULTIPLY THE RESULT BY
COS 2πK/N
ADD THE RESULT TO
REGISTER 2
SK IS STILL AVAILABLE AT THE INPUT OF THE
MULTIPLIER, MULTIPLY IT BY SIN 2πK/N
ADD TO THE CONTENT
OF REGISTER 3
INCREMENT
K
WAIT FOR NEW
SAMPLES
NO
K=N-1
YES
DIVIDE REGISTER 2
BY REGISTER 3
FIND SUM OF SQUARES
OF REG 2 AND 3
REPORT
IT TO
REMOTE
GOING TO ARCTAN TABLE IN
PROM FIND THE ANGLE
COMPARE TO REFERENCE
TO DISPLAY 'OVERHEAD'
DISPLAY THE
ANGLE

7. DATA LINK, CONTROLS AND DISPLAY

7.1 The Concept

To ensure correct timing sequences of all functions, as well as stability of transmitted tones, a crystal controlled Master Clock (Frequency = 1.76 MHz) is used for the entire system. This clock will control all transmit and receive functions at a particular site so that one clock will be at the local site and a second one at the remote site.

7.1.1 Conversion and Transmission

All data to be transmitted should be in Binary or BCD format. A 32 stage Parallel-to-Serial out shift register converts the data to serial form and sends it to the FSK Modulator. The clock rate is 333.3 Hz (derived from the 1.76 MHz Master Clock). The data steam is initiated by a start signal whose frequency is either 10 Hz (local → remote direction), or a fraction of this frequency, as determined by the Integration Constant selected (for the remote → local direction).

The FSK Modulator synthesizes a sinewave of 2573 or 2794 Hz from the Master Clock. The synthesizer uses 9 steps so that the required clock frequency is 18 times the output frequency. This frequency is derived by dividing the Master Clock by either 38 or 35 depending on whether the transmitted bit is a 0 or a 1.

When no data is transmitted, the synthesizer generates a steady signal of 2573 Hz.

Audio signals may be either from the received radio signals, or the optional telephone facility. These signals are passed through a 2.3 kHz low pass filter to eliminate unwanted signals in the data band and the audio and data tones are combined in a mixer. A buffer amplifier provides the proper power levels and source impedance for the telephone line.

7.1.2 Reception and Data Recovery

At the receiver end of the link the audio and data signals are separated using a 2.3 kHz low pass filter (for the audio) as well as band pass filters for each of the desired tones.

A carrier detector monitors the data tones to activate the System Alarm if these tones are interrupted. The FSK Demodulator recovers the data in serial form and sends it to the Serial-to-Parallel Converter. The Serial-to-Parallel Converter consists of a 32 stage Serial-In/Parallel Out Shift Register whose clock is initiated by the reception of the START Bit. The leading edge of the START Bit triggers the circuits which divide the Master Clock at this site by 2640 to obtain an initial clock frequency of 666.7 Hz.

A further flip-flop divides this by 2 again to get the 33.3 Hz rate required by the shift register. This 2 stage division is used to ensure that the clock advances the register at the centre of the received bit to allow for deteriorated pulse widths and slight discrepancies in the clock rates of the transmitter and receiver.

When the START Bit appears at the last stage of the shift register, the circuit checks for the presence of the STOP Bit in the first stage and then stops the register clock. A 'Data Complete' strobe is sent to the associated peripheral circuitry to signal that the data is now valid and available for the appropriate processing (displays, switches, etc.). The register clock circuitry is also reset so that reception of a new START Bit can trigger the proper sequence of events. Checking for both the START and STOP Bits provides a primitive form of error detection to check the data stream for proper format. More complex forms of error detection (e.g. parity bits) were thought to be unnecessary since the data is updated every 1/10 of a second or so and an error in a display would be corrected in the next transmission causing, at worst, a slight flicker in the display. If any signals are critical, a certain number of samples could be polled before a change is initiated (e.g. channel switching, antenna tests, etc.).

7.1.3 Channel and Bearing Display

There are two displays: the main display and a secondary display which may be used to store readings. It is proposed that the circuitry for both displays is essentially identical with the data inputs operating in parallel. The secondary display is always updated just prior to the latching of new data but will be blanked in normal operation. If a reading is to be stored, a circuit will latch and unblank the secondary display which will now show the last reading received before the store function was activated. Return to normal operation will again blank the secondary display and unlatch it so that it will now be updated again.

Storage and Display of channel numbers and bearings will occur under the following conditions:

1. A manually activated 'store' switch is operated by the controller to preserve a reading while he monitors a different channel.

2. If the system is in the AUTO EMERGENCY SWITCHOVER mode, the data received just prior to switchover will be preserved in the secondary display.

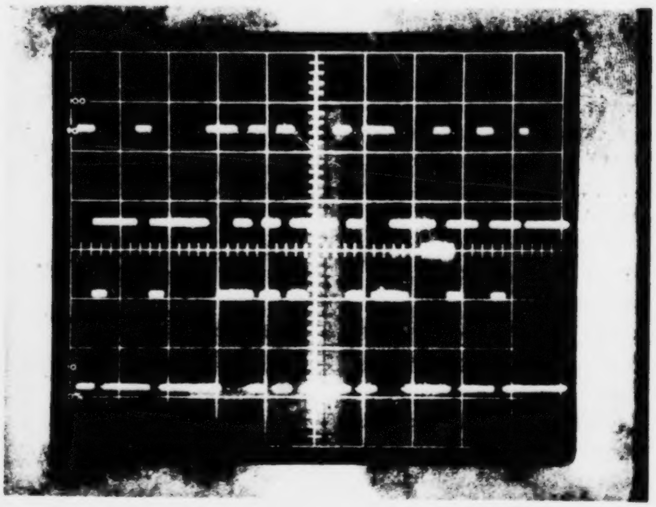
3. If a SYSTEM ALARM, or DATA INVALID condition is encountered, the last valid reading is stored.

7.1.4 Summary

As indicated in the introduction, all the circuits mentioned were constructed in 'breadboard' form and tested. Transmission of the data was reliable and the encoding and decoding circuitry worked satisfactorily. Fig. 7.1 is a photograph showing the data at the output of the Parallel-to-Serial converter (upper trace) and at the input of the Serial-to-Parallel converter (lower trace). Except for the 3 msec. delay caused by the receiving filters, the traces are essentially identical. The proposed next step is to construct the sections on printed circuit cards and to work out the details of the control circuitry (channel selection, etc.)

FIG. 7.1

DATA TRANSMISSION LINK (FSK MOD AND DEMOD)



Time = 10 msec./Div.
Sensitivity = 5V/Div.

Data as seen on the output of the Parallel-to-Serial Converter (= Input to FSK Modulator)

Data as seen on the input of the Serial-to-Parallel Converter (= Output to FSK Demodulator)

There is a delay of approximately 3 msec. caused by the tone filters. Otherwise, the transmitted and received data is identical.

7.2 Improvements and Modifications

Further work has been done on the details of the control console. Provisions have been made to avoid erroneous operation of critical circuits, such as accidental channel changes due to noise or missing or extraneous bits in the data stream. The design for the display and control sections in the operator's console is now complete and a suitable mechanical enclosure for the console has been selected. Printed circuit board layout has been initiated for several of the circuits. The remainder of the circuitry has been finalized so that appropriate printed circuits can be ordered as soon as the mechanical design is accepted.

7.2.1 Security of Critical Data and Control Functions

It was suggested previously that critical data could be made secure by the polling of several updates to ensure the integrity of such data. This idea was abandoned as it would introduce unnecessary delays in the initiation of some functions. Almost all of the critical functions are at the receiver end of the link and since there was a considerable number of spare bits in the 'console to receiver' direction, it was decided to use two of these bits (at different positions in the data stream) for each of the critical functions. The relevant bits are compared at the other end of the link and the new information will then only be accepted if the status of those two bits is identical. In this way, any change can be made as fast as the information is transmitted, but the validity of the change would also be established before the command is carried out.

Functions which fall into this category are:

Channel Selection

Remote Power On/Off

Antenna Simulator (System Test), and

QDR/QDM Selection

In the receiver-to-control path, only the 'Emergency Reception' needs to be secure, otherwise it might initiate an automatic switchover to the emergency channel.

7.2.2 Local/Remote Control of the Receiver

For installation and maintenance purposes, it is desirable to be able to operate the receiver at the actual receiver site. A switch on the receiver can disconnect the control signals from the data link and connect them instead to a control panel at the receiver site. The signals for the displays on the controller's console, however, stay connected and the operator is advised that the receiver is no longer under his control by displaying a symbol 'S' (Service) on the control panel.

7.2.3 Automatic Emergency Operations

A feature of the equipment is the ability to automatically switch to the emergency channel if an emergency transmission is received. Since this function is under the control of the operator and most of the associated functions are affecting the console (e.g. storage or previous data and return to the original channel at the end of the emergency transmission) it was decided to incorporate the switchover circuit in the console, rather than in the receiver. If the feature is enabled and the emergency receiver detects a signal, then the console will send out the code for the emergency channel. Thus, the DF receiver will switch over to the emergency channel, just as if the operator had selected it. Shortly after the emergency transmission ceases, the original channel code will be sent out again and the DF receiver will return to the original channel.

7.2.4 Displays

The equipment may be operated under various lighting conditions, hence a brightness control is incorporated in the display to regulate the brightness of all indicators with the exception of the 'System Alarm'. The latter operates at full brightness all the time. To facilitate the identification of the various indicators under subdued light conditions, it is proposed to use 7-segment displays for all indicators and to wire them so they will show meaningful letters (e.g. 'S.O.' for 'Signal Overhead' and 'E' for 'Reception on the Emergency Channel'). Larger characters would be used to emphasize the most important displays (e.g. main bearing and channel number, and the system alarm).

It was decided to omit the 'Data Valid' indicator which was suggested in the original proposal. Instead, the main display will be blanked if the reading is not valid, while the last reading would be shown in the 'Stored' display

7.2.5 Controls

It was decided to implement the channel selection with 13 pushbutton switches (for channels 1 to 12 and the emergency channel) which are electronically interlocked. Separate illumination of these switches is considered to be unnecessary since the selected channel number is shown as part of the digital display.

The four position antenna simulator (System Test) uses momentary pushbutton switches which, at the same time, activate the test feature itself, as well as selecting the desired (simulated) reading.

Rotary switches allow the selection of three different scanning rates for the antenna commutator and the selection of one of four integration constants. Single pushbutton switches are used for the QDR/QDM selection, the 'Lamp Test' and the 'Alarm Reset'. Auto or manual emergency channel selection and remote control of the receiver power are operated by toggle switches. Potentiometers are used to control the volume of the built-in loudspeaker and the brightness of the display.

This layout was later modified to a rack construction after introducing the direct access dialing and a circular bearing display.

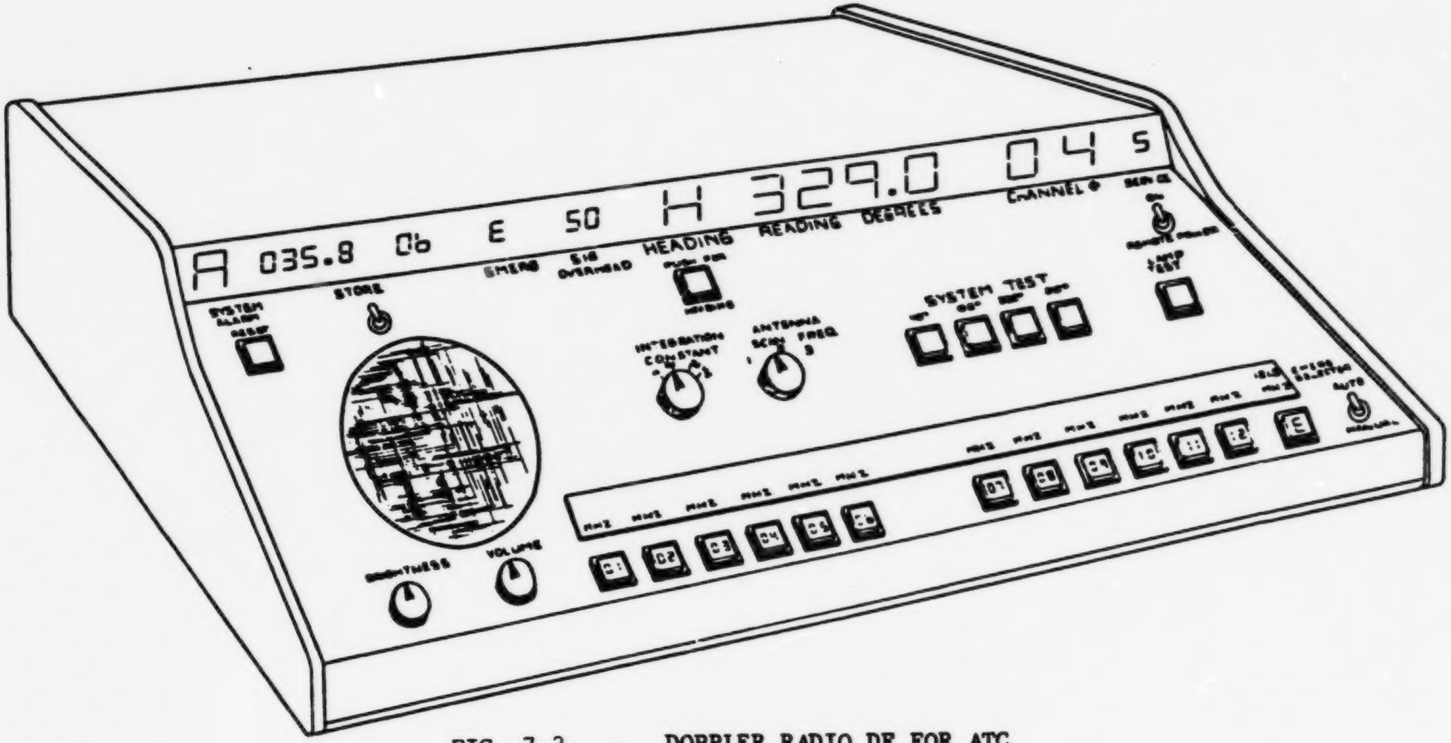

A 035.8 06 E 50 H 329.0 04 S
SYSTEM ALARM
STORE
HEADING
READING
DEGREES
CHANNEL
SYSTEM TEST
LAMP TEST
INTEGRATION CONSTANT
ANTENNA SCAN FREQ
BRIGHTNESS
VOLUME
AUTO

FIG. 7.2 - DOPPLER RADIO DF FOR ATC

CONTROL AND DISPLAY CONSOLE

FIRST PROPOSAL

7.3 Direct Access Dialing Frequency Selection

Direct dialing access to all 720 channels of the Aeronautical VHF Band was not included in the original specifications which called for a number of preset frequency channels. Due to new developments in the market, it is now considered important to have this capability included as an option. An amendment to the original contract was received to cover the additional design work.

The control concept of the DF system was based on the original contract calling for preset channel selection. Much of the design and development had already been completed at the time of the amendment, and a decision was taken to provide the direct frequency dialing as an option, compatible with the original design. Owing to limited data bandwidth the keyboard and modems were designed to handle one digit at a time and thus the frequency selection has to also be done one digit at a time. On the receiver side, circuitry was included to decide if the incoming information addressed the preset channel selector or the frequency selector.

The channel selector looks at the first incoming digit. If it is a valid channel (0 through 9) or an 'E' (for 'Emergency Channel') then the channel selector will disable the frequency selector and generate the information code required for the receiver synthesizer. If the first digit is an 'F' (for 'Frequency Selection') then the channel selector is disabled and the frequency selector is enabled. The frequency selector stores the next 6 digits for further processing and also echoes the digit(s) back to the control via the telephone link.

If, at any time during the dialing sequence, an 'R' (= Reset) is received, the memory will be cleared and the dialing sequence has to be started from the beginning.

Once all 6 required digits have been sent, the frequency selector generates an 'information complete' signal and the entire combination is loaded into the synthesizer programming circuit. This circuit has to translate the 6-digit frequency combination (in BCD form) into the binary code required by the frequency synthesizer of the receiver.

The translation is done as follows:

The first digit (which should always be a '1') is ignored and the other five digits are stored in a presettable decade counter. A clock then causes the counter to count down until it reaches zero. Now the clock is disabled.

The same clock is also divided by 25 (to allow for 25 kHz channel spacing) and fed to a binary counter (originally preset to 1463). This circuit also counts down and when the clock stops, the remainder at the outputs is the required binary code. A set of 3-state buffers allows this code to be fed to the Receiver synthesizer circuits if frequency selection, rather than channel selection, is desired by the operator.

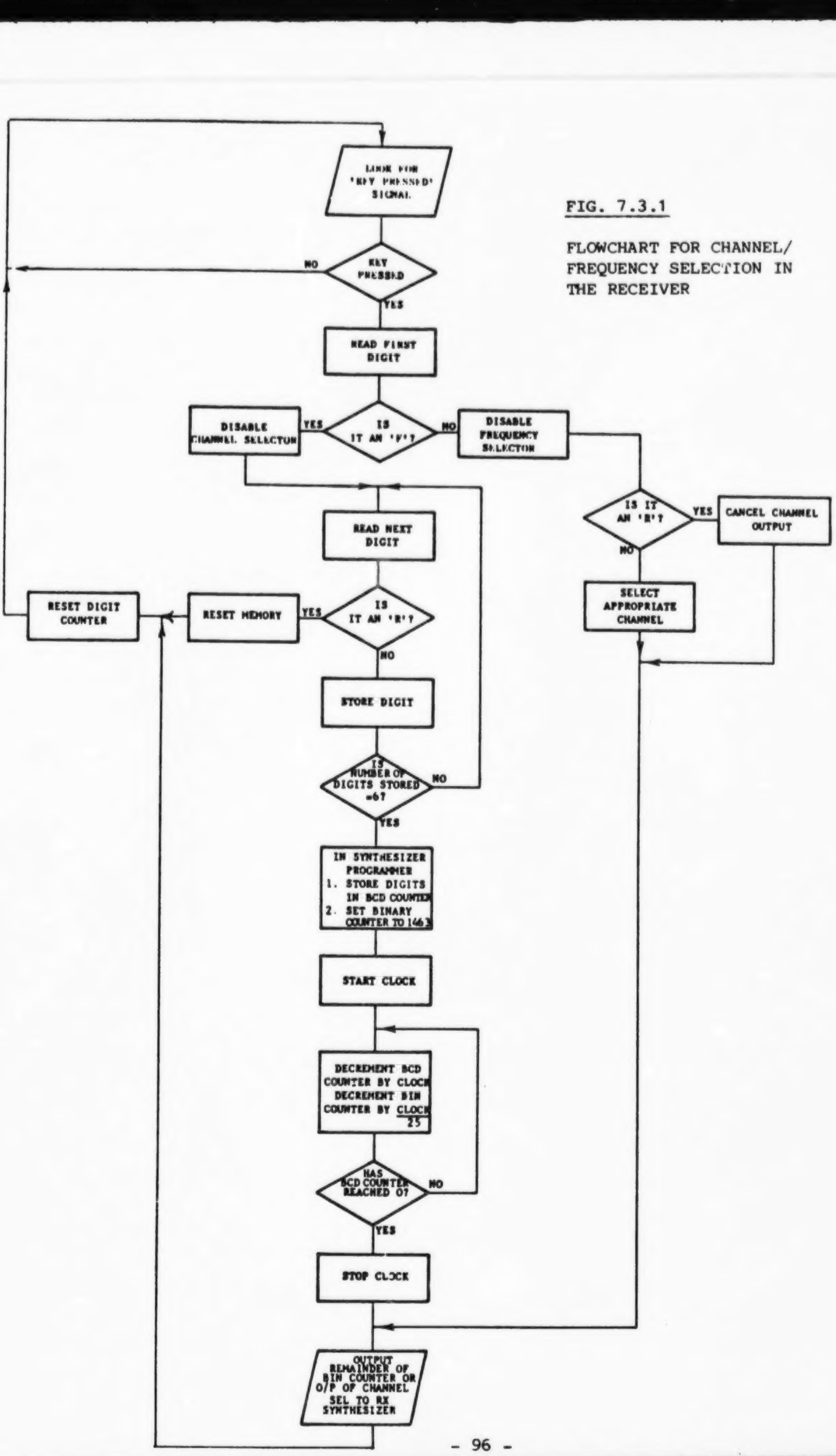

LOOK FOR 'KEY PRESSED' SIGNAL
KEY PRESSED
NO
YES
READ FIRST DIGIT
IS IT AN 'F'?
YES
NO
DISABLE CHANNEL SELECTOR
DISABLE FREQUENCY SELECTOR
IS IT AN 'R'?
YES
NO
CANCEL CHANNEL OUTPUT
SELECT APPROPRIATE CHANNEL
READ NEXT DIGIT
IS IT AN 'R'?
YES
NO
RESET MEMORY
RESET DIGIT COUNTER
STORE DIGIT
IS NUMBER OF DIGITS STORED =6?
NO
YES
IN SYNTHESIZER PROGRAMMER
1. STORE DIGITS IN BCD COUNTER
2. SET BINARY COUNTER TO 1463
START CLOCK
DECREMENT BCD COUNTER BY CLOCK
DECREMENT BIN COUNTER BY CLOCK/25
HAS BCD COUNTER REACHED 0?
NO
YES
STOP CLOCK
OUTPUT REMAINDER OF BIN COUNTER OR O/P OF CHANNEL SEL TO RX SYNTHESIZER

FIG. 7.3.1

FLOWCHART FOR CHANNEL/ FREQUENCY SELECTION IN THE RECEIVER

Provisions were made to allow the Receiver control circuit to operate without the frequency selector (channel selection only) or without the channel selector (frequency selection only) or using both features, to allow the customer to tailor the unit to his requirements.

All required circuits were designed and verified in the breadboard stage. The appropriate printed circuit cards have been ordered. The direct frequency dialing option will require three extra printed circuit cards in the Receiver Control and one card in the Operator Control/ Display Unit. A flowchart for a channel frequency selector is shown in Fig. 7.3.1.

7.4 Development of a Circular Bearing Display

In the Doppler DF, the receiver bearing processor provides a 4 digit, BCD encoded reading for the bearing (or heading). This is transmitted via the data link to the controller's console and displayed on a 4-digit, 7-segment LED display. However, to assist the controller in his orientation, it is desirable to also give the direction using a circular display with sufficient resolution indicating the relative position of the plane. In consultation with the customer's representatives, it was decided that a 5" resolution LED display would be suitable. This means using 72 individual LED's with the associated decoding circuitry.

In order to keep the decoding circuitry simple, it was decided that a '0' LED would mean an actual value between 0° and 4°, while a '5' LED would light when the reading is between 5° and 9°. This would be repeated for every decade (i.e. 0, 5, 10, 15 .... to 355). Individual addressing of all 72 LED's was discarded as being too complex and a matrix approach was adopted with common lines for the 'tens' and common lines for the 100's.

The lines for the units are decoded to decide if the unit's digit is less than 5 or equal to, or more than 5.

The concept is shown in the schematic diagram. Two BCD to Decimal decoders (IC1 and IC2) are used to decode the tens and hundreds digits, while a combination of gates is used to decode the unit's digit. Tens driver transistors Q1 to Q10 apply a positive voltage to all LED's which have the same tens digit (e.g. 10, 110, 210 and 310). The 'hundreds' decoder outputs are further split using ANDgates and the proper transistor (Q11 to Q18) is selected on the basis of the hundreds output (IC2) and the output of the units decoder. This will apply a ground to the cathode of the appropriate LED.

Intensity modulation is achieved by inverting the system intensity control line and using this signal to modulate the 'D' input of the hundreds BCD decoder. This will cause the selected LED cathode to be turned on and off with a duty cycle set by the intensity control.

The circuit was built up as a 'breadboard' and the proper operation was verified. A printed circuit layout was made and printed circuit boards are currently in production to be used for the prototype DF units.

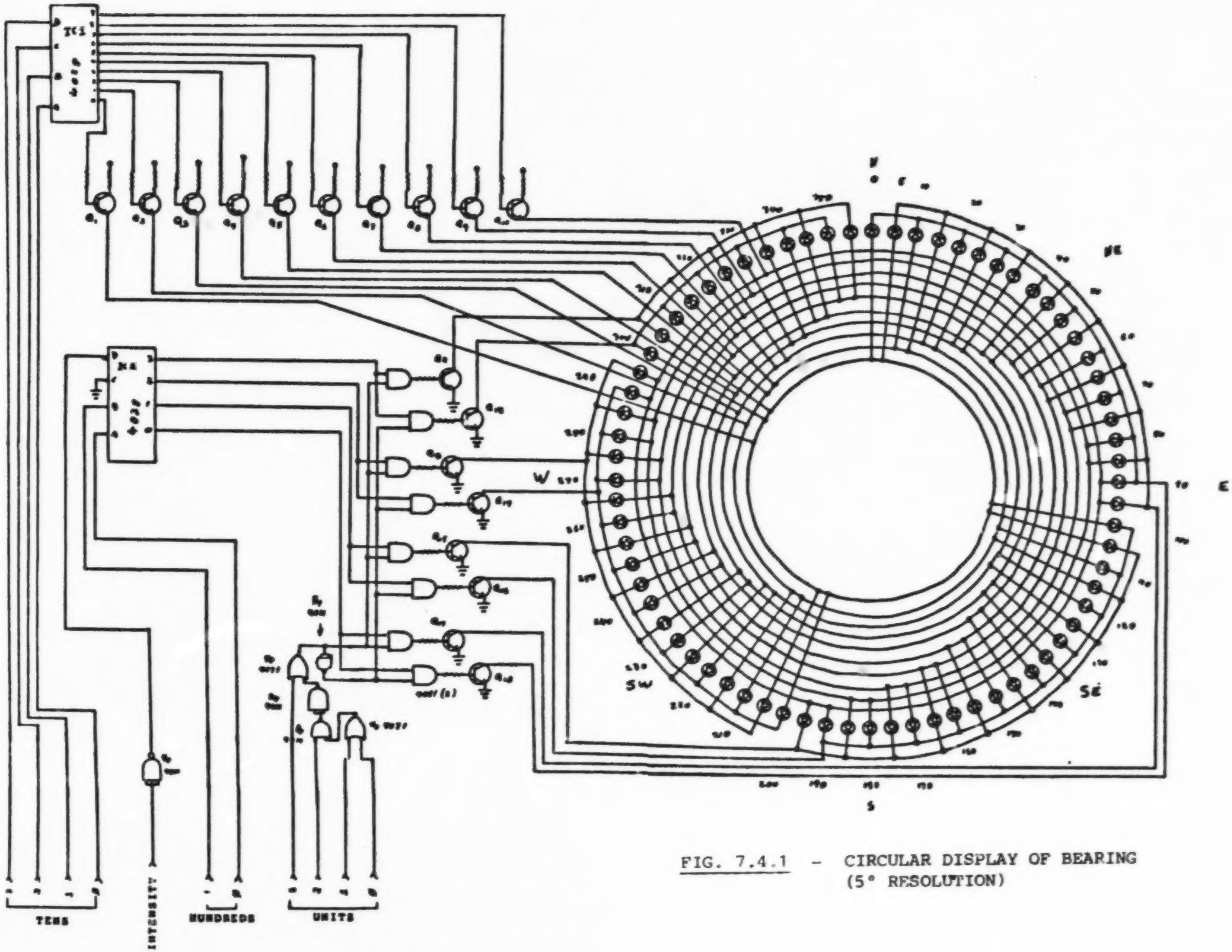

N
NE
E
SE
S
SW
W
TENS
INTENSITY
HUNDREDS
UNITS
4029

FIG. 7.4.1 - CIRCULAR DISPLAY OF BEARING (5° RESOLUTION)

7.5 Final Arrangement of Controls

A new operator's control display panel was designed to accommodate the capabilities of channel selection or direct frequency dialing.

The selection pushbuttons now have a dual role - frequency or channel selection which can be chosen by operating the frequency mode pushbutton. When operating in the channel selection mode, the channel indicator lights become illuminated; or in the frequency selection mode, the dialed frequency is indicated on the LED readout. In addition, the new panel contains a circular bearing display made up of 72 LED point dials which show the approximate portion of the aircraft.

This new panel layout is shown in Fig. 7.5.1.

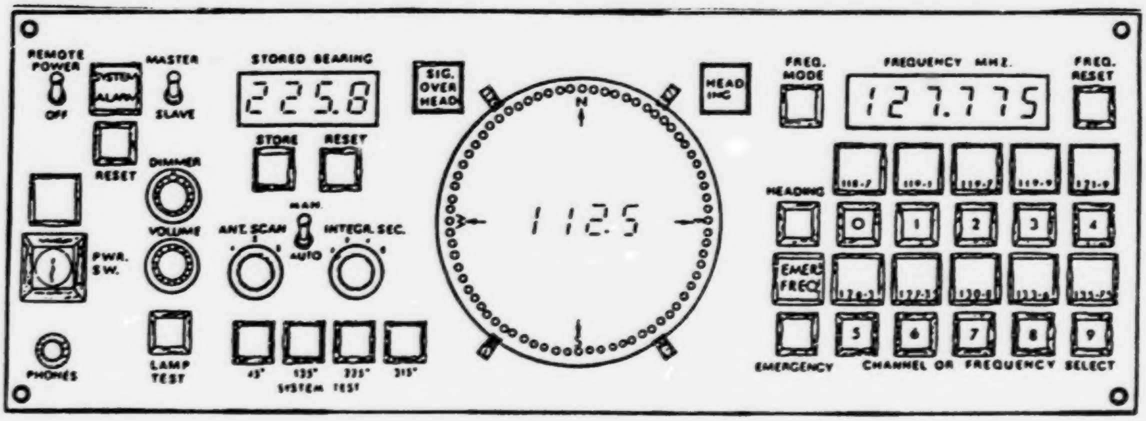

REMOTE POWER
OFF
SYSTEM ALARM
MASTER
SLAVE
RESET
DIMMER
VOLUME
PWR. SW.
PHONES
LAMP TEST
STORED BEARING
225.8
STORE
RESET
MAN.
AUTO
ANT. SCAN
INTEGR. SEC.
45°
135°
225°
315°
SYSTEM TEST
SIG. OVER HEAD
N
112.5
HEAD ING
FREQ. MODE
FREQUENCY MHZ.
127.775
FREQ. RESET
HEADING
0
1
2
3
4
EMER. FREQ.
5
6
7
8
9
EMERGENCY
CHANNEL OR FREQUENCY SELECT

FIG. 7.5.1

OPERATOR'S CONTROL/DISPLAY PANEL, CONTROLS AND INDICATORS

8. SYSTEM OPERATION

8.1 Evaluation of Sub-systems and Functional Blocks

8.1.1

Prior to integration of the complete DF system, an evaluation was made of every one of the functional sub-systems incorporated in the equipment, so as to verify their performance is in agreement with the design targets. For this purpose, a number of test jigs have been designed and constructed to simulate the respective sub-system interfaces so that each one can be put in operation outside of the complete system. The following comments reflect the performance status and any final design changes which had to be incorporated in order to meet the target requirements.

8.1.2

Antenna array operation was verified on the field site, using an external transmitter and instrumentation to measure voltage and phase. The results were recorded in section 5.6 of this report. Those were considered acceptable for operation in the system.

8.1.3

The antenna commutator was tested and aligned using an antenna simulator constructed for this purpose and consisting of a network of delay lines to provide 16 outputs at different phases, simulating a signal arriving from a target transmitter.

8.1.4

The twin-channel DF receiver was tested as a separate entity, observing gain, dynamic range, noise figure bandwidth, and the phase matching between the channels. As a consequence, the RF amplifier had to be modified in order to meet the required 7 dB noise figure and a different circuit was substituted for the phase detector, to make it accept phase differences up to ±180° with a linear response. Amplitude limiting originally provided was found marginal and had to be increased by an additional 60 dB. The resulting circuit was found to meet the system requirements.

8.1.5

The frequency synthesizer was examined, together with its digital control network. The output range and the controls were reported functional, but the VCO has shown a tendency to jump out of lock at the high end of the band when subjected to temperature variations. At this point, it was decided to carry on with this module for the system tests and to replace it with a new, corrected design in approximately three months time.

8.1.6

The bearing processor was made operational and its program was tested in the presence of noise, using a test jig built to simulate the operational interface with the receiver.

8.1.7

The audio and the emergency receivers have been put together and tested with a temporary set of crystal filters which did not meet the procurement specifications, giving 40 dB instead of 60 dB adjacent channel rejection. New filters were placed on order but delays in delivery have not made it possible to make the replacement on time. It is expected to correct this deficiency within the next four weeks.

8.1.8

The control/display and data transmission sub-system was fully tested separately from the receiver and bearing processor, by using a test jig designed to provide the operational interfaces. The local-remote transmission link was tested in a loop-back through the local telephone exchange, using the combined data-above-voice transmission. In addition, a test was made to simulate the specified 10 km distance of a telephone line. Both sets of results were highly satisfactory.

8.1.9

Finally, the receiver-antenna unit interface operation was checked with the maximum length of the RF and control cables (150 ft.) with acceptable results.

8.2 DF Field Trials

8.2.1

Following the sub-system evaluation, and any corrections to make the individual units operational, the integration of the DF system was carried out with the intention to demonstrate its performance at the Company's Field Test Site in Granby.

8.2.2

The Test Site is an open field, substantially flat and free from trees and other obstacles, particularly any metallic objects like wires, posts, rails, pipes, etc. A gravel road runs through the centre of the field and a test hut is erected within easy access to the road. The hut is circular, 8 ft. high and 16 ft. in diameter, with a flat disk roof. Both the roof and the walls of the hut are covered with metal mesh to form a body of revolution of electric reflecting surface. A hydraulic mast is placed in the centre of the hut, capable of being raised and rotated by remote controls.

A diesel operated generator provides power for the mast controls, the instrumentation and the equipment under test. All the equipment, the generator and cables are enclosed within the hut's circular shield so as not to introduce any reflection irregularities.

8.2.3

The DF antenna was mounted on top of the hydraulic mast, capable of being elevated 10 ft. above the roof or 18 ft. above the ground level. The connecting cables were installed to run into the enclosure via the centre opening, alongside the mast. The DF system was tested with the receiver unit control only, since it was considered unnecessary to connect up the operator's control/display unit at this stage.

8.2.4

A target transmitter was erected in an auxiliary shack some 40 ft. away from the test hut in a direction perpendicular to the road. The transmitter consisted of a signal generator, a vertical dipole and a portable power generator unit. Frequency and level of the transmission were controlled by an operator in communication by radio with the test hut. A circle of 400 ft. radius was assured free of re-radiations by removing any vehicles or equipment. A photograph of the test site and the DF installation is shown in Figure 8.2.4.1. Figure 8.2.4.2 shows a sketch of the test site superimposed on a survey map.

8.2.5

A preliminary test was run on the bearing accuracy of the DF system by rotating the antenna with a fixed target transmitter and comparing the obtained bearings with the physical angular positions of the array. The results of this initial test are shown in Figure 8.2.5.1 (dated January 7, 1982) showing the instrumental bearing error as a function of the angle of antenna rotation. The results of this test were not considered satisfactory and the equipment was dismantled for troubleshooting.

8.2.6

Particular attention was given to checking the phase match of the dipole cables, the antenna receiver interfacing, the receiver phase balance and bearing processor software. On completion of this exercise, the equipment was re-assembled and a second set of tests was made, showing considerably better results (dated January 15, 1982), this time within the design specifications. It was at this point that a demonstration was arranged for TDC on January 19, 1982. The results summary is shown in the Table, paragraph 8.3.1.

FIGURE 8.2.4.1

FIELD TEST SITE

View of the Circular Test Hut
and the target transmitter

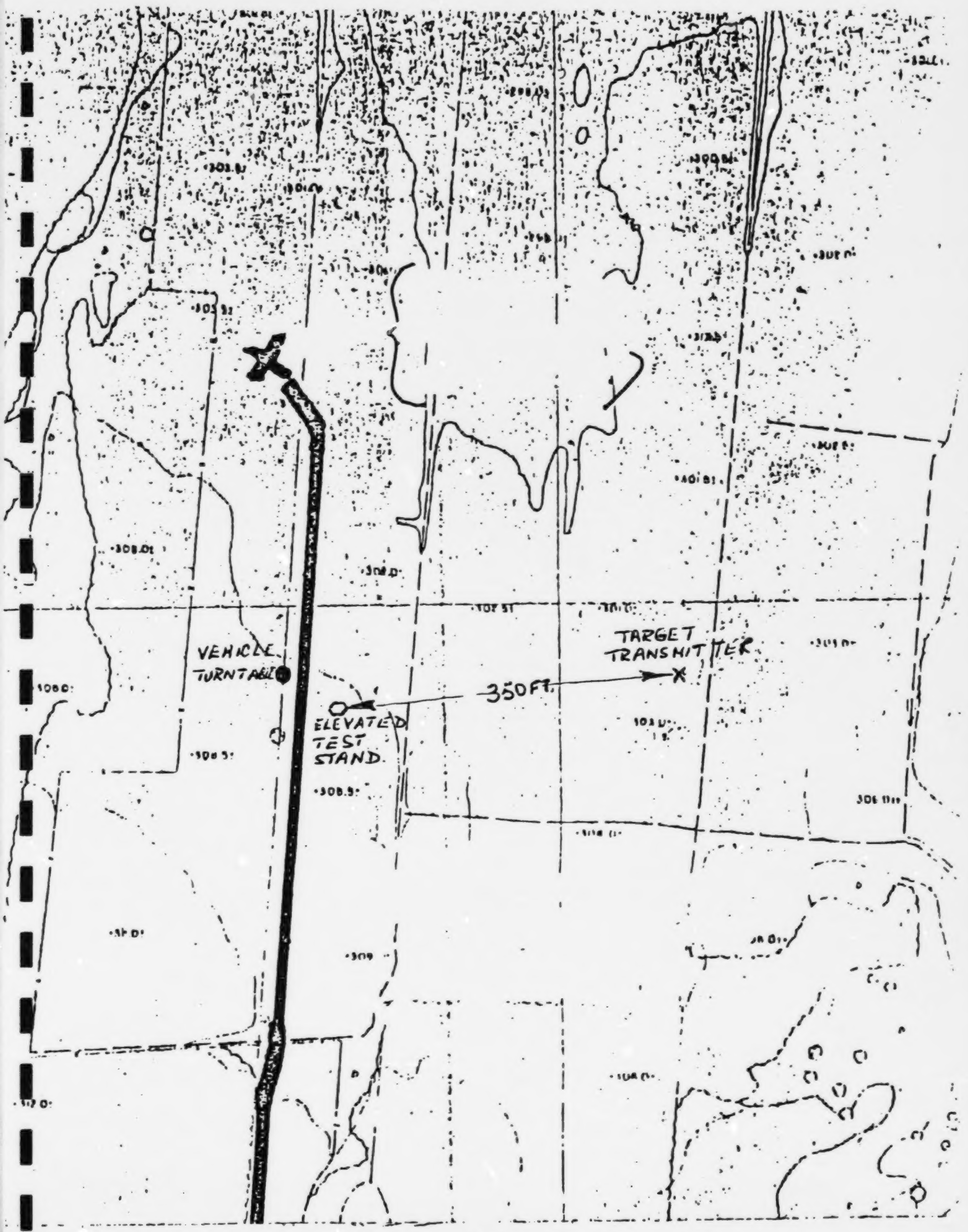

VEHICLE TURNTABLE
ELEVATED TEST STAND
350FT
TARGET TRANSMITTER
308.01
308.0
308.5
309

FIG. 8.2.4.2 - PLAN OF TEST SITE

8.2.7

A final test was run on January 29, 1982, as a check on performance prior to dismantling the equipment for shipment to the installation site at Kingston Airport, where it was due in the first week of February 1982. A graph of DF bearing accuracy, shown in Figure 8.2.7.1, demonstrates that the results are repeatable and the instrumental DF accuracy is now acceptable.

8.2.8

Direction finding with antenna array, made up of a finite number of dipoles, leads to the existence of the so called 'spacing errors'. These errors are at a maximum at approximately 0.25 and 0.75 of the distance between the adjacent dipoles, and they become smaller and smaller as the number of dipoles in the array is increased.

A separate test was made to demonstrate the magnitude of the spacing errors by taking bearing measurements every 1° of rotation. These are shown in Figure 8.2.8.1 for the sector of the array centred on the 'North' reference. The results show the spacing errors to be quite undetectable.

8.2.9

Tables of individual test readings which were used for construction of the graphs, Figures 8.2.5.1, 8.2.8.1, 8.2.7.1 are attached in Appendix A1 - A3 respectively.

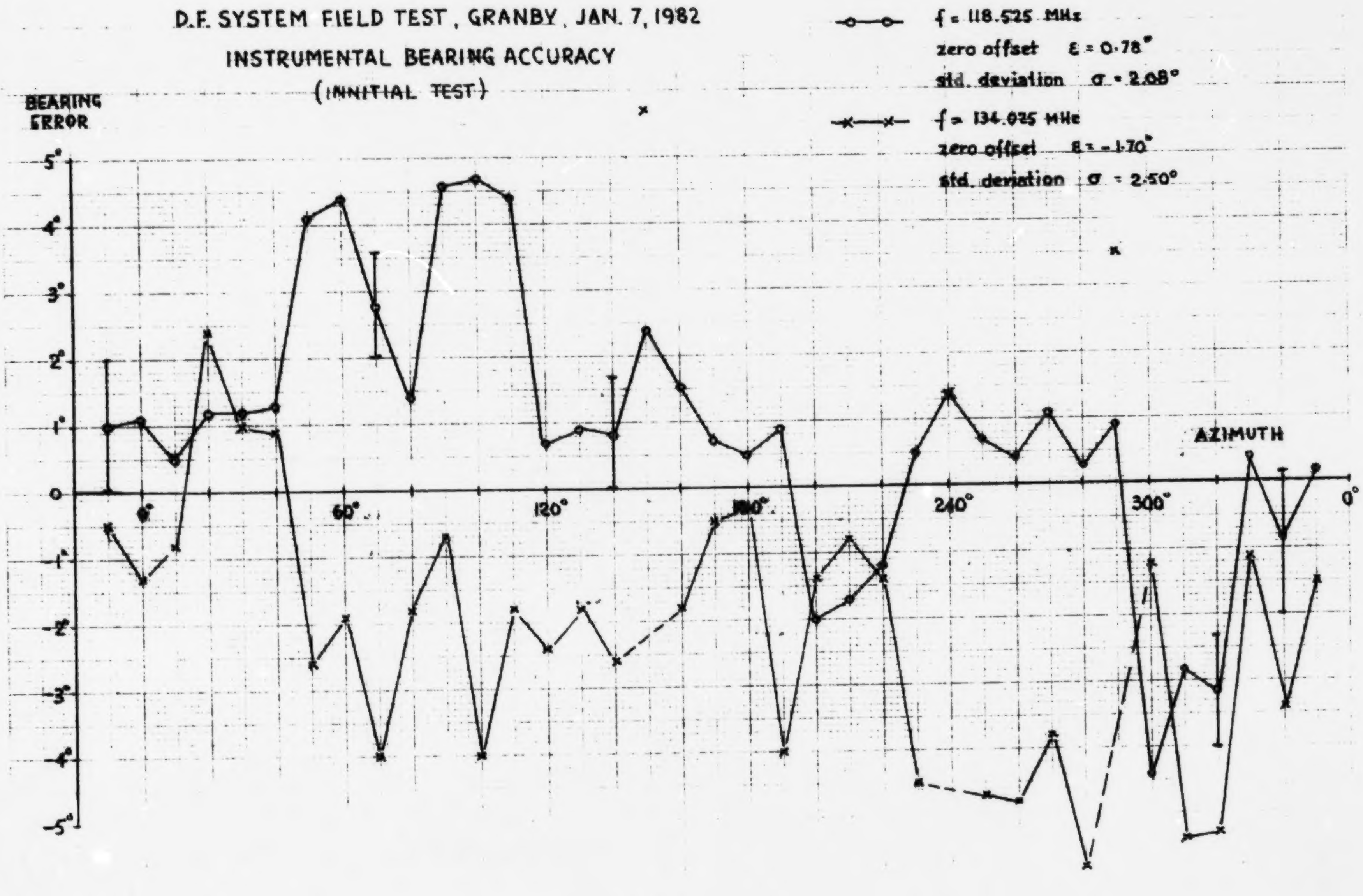

D.F. SYSTEM FIELD TEST, GRANBY, JAN. 7, 1982
INSTRUMENTAL BEARING ACCURACY
(INNITIAL TEST)
f = 118.525 MHz
zero offset ε = 0·78°
std. deviation σ = 2.08°
f = 134.025 MHz
zero offset ε = -1.70°
std. deviation σ = 2.50°
BEARING ERROR
5°
4°
3°
2°
1°
0
-1°
-2°
-3°
-4°
-5°
0°
60°
120°
180°
240°
300°
0°
AZIMUTH

FIG. 8.2.5.1

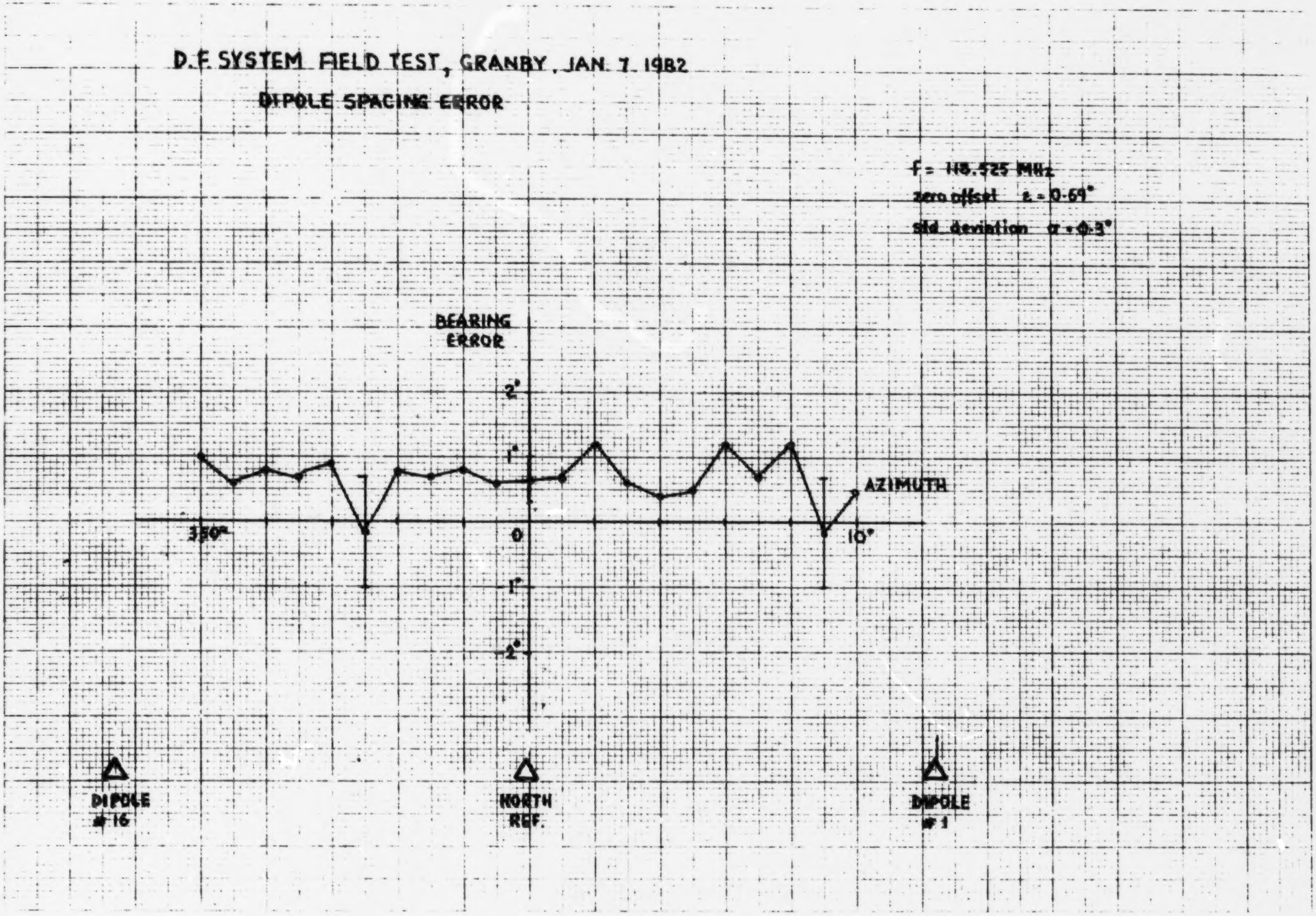

D.F. SYSTEM FIELD TEST, GRANBY, JAN. 7 1982
DIPOLE SPACING ERROR
f = 118.525 MHz
zero offset ε = 0.69°
std deviation σ = 0.3°
BEARING ERROR
2°
1°
0
1°
2°
350°
10°
AZIMUTH
DIPOLE #16
NORTH REF.
DIPOLE #1

FIG. 8.2.8.1

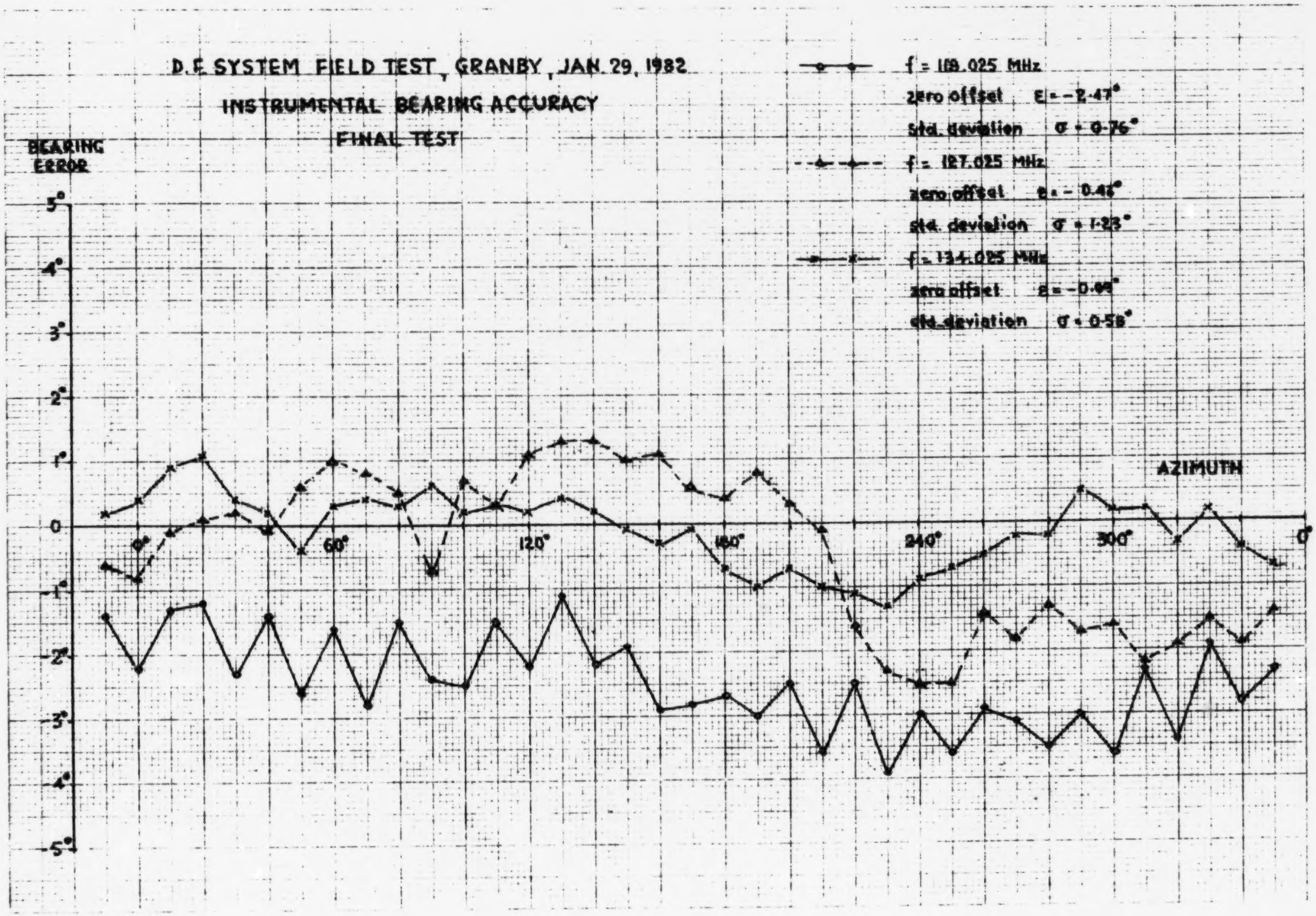

D.F. SYSTEM FIELD TEST, GRANBY, JAN. 29, 1982
INSTRUMENTAL BEARING ACCURACY
FINAL TEST
BEARING ERROR
5°
4°
3°
2°
1°
0
-1°
-2°
-3°
-4°
-5°
0°
60°
120°
180°
240°
300°
0°
AZIMUTH
f = 118.025 MHz
zero offset ε = -2.47°
std. deviation σ = 0.76°
f = 127.025 MHz
zero offset ε = -0.48°
std. deviation σ = 1.23°
f = 134.025 MHz
zero offset ε = -0.09°
std. deviation σ = 0.58°

FIG. 8.2.7.1

8.3 Field Test Results

8.3.1 Instrumental Bearing Accuracy
(Spec : Bearing rms Error ≤±1.5°)

	Initial Test 07.01.82	Second Test 15.01.82	Final Test 29.01.82
Frequency 118 MHz			
Zero offset	0.78°	2.3°	-2.47°
Max. Deviation	±4.7°	±1.5°	±1.4°
Std. Deviation (rms error)	2.08°	0.6°	0.76°
Frequency 127 MHz			
Zero offset	-	5.1°	-0.43°
Max. Deviation	-	±3.0°	±2.0°
Std. Deviation (rms error)	-	1.4°	1.23
Frequency 134 MHz			
Zero offset	-1.70°	0°	-0.09°
Max. Deviation	±4.0°	±1.5°	±1.0°
Std. Deviation (rms error)	2.50°	0.5°	0.58°

8.3.2 DF Sensitivity (Spec. sensitivity ≤3 μV for ±1.5° noise error)

Measured ≤5 μV/m for a noise fluctuation of ±2°
(corresponding to 10 dB S/N ratio for a field strength of 3.2 μV/m)

8.3.3 Dipole Spacing Error (included in bearing accuracy spec.)

Measured at 118 MHz rms error 0.3° due mostly to noise.

9. CONCLUSIONS AND RECOMMENDATIONS

9.1 Completion of the Development Phase

With the satisfactory demonstration of DF performance, and the feasibility of the design concept, the development phase of the VHF Doppler Radio DF system is hereby completed. The engineering prototype, on final tests in Granby, can be transferred now to the installation site assigned by TC at Kingston Airport.

9.2 Follow-up Stages of Work

The installation of the equipment at the appointed site, and placing it in operation, will be performed under a separate contract under negotiation. In the course of this work, replacements will be made of the modules reported to be deficient: the frequency synthesizer module and the IF crystal filters for the audio and the emergency receivers. This will be followed by preparation of the required documentation - drawings and manuals.

APPENDIX 1

TABLE A1

TITLE: DF INSTRUMENTAL ACCURACY TEST
(see graph, Fig. 8.2.5.1, p.106)

DATE: January 7, 1982

TEST CARRIED OUT BY: J. Noiseux and R. Luc

AT: Bayly, Granby Field Test Site

AZIMUTH	Fo = 118.520 MHz (-20dBm) Fo tune = 118.525 MHz	Fo = 134.020 MHz (-20dBm) Fo tune = 134.025 MHz Fo du Lo = 164.026 MHz (-10dBm)
350°	348-350	349.5
0	1.1	358.7
10	10.5	9.2
20	21.2	22.4
30	31.2	31.0
40	41.3	40.9
50	54.1	47.4
60	64.4	58.1
70	72-73.6	66
80	81.4	78.2
90	94.6	89.3
100	104.7	96
110	114.4	108.2
120	120.7	117.6
130	130.9	128.2
140	140-141.7	137.4
145		142.7
150	152.4	155.7
160	161.5	158.2
170	170.7	169.5
180	180.5	179.7
190	190.9	186.
200	198.	198.6
210	208.3	209.2
220	218.8	218.6
230	230.5	225.5
240	241.4	241.4
250	250.7	245.3
260	260.4	255.2
270	271.1	265.2
280	280.3	274.2
285		283.7
290	290.9	293.5
300	295.6	298.8
310	307.2	304.6
320	316-317.7	314.7
330	330.4	328.9
340	338-340.1	336.6
350	350.2	348.5

APPENDIX 2

TABLE A2

TITLE: DF SYSTEM FIELD TEST - DIPOLE SPACING ERROR (see graph, Fig. 8.2.8.1, p. 107)

DATE: January 7, 1982

TEST CARRIED OUT BY: J. Noiseux and R. Luc

AT: Bayly, Granby Field Test Site

AZIMUTH	Fo = 118.520 MHz Fo tune = 118.525 MHz	Fo = 134.020 MHz (-20dBm) Fo tune = 134.025 MHz Fo du Lo = 164.026 MHz (-10dBm)
350°	351.0	348.7
351	351.6	351.0
352	352.8	350
353	353.7	353.6
354	354.9	354.5
355	354-355.7	356.1
356	356.8	2.4
357	357.7	1.5
358	358.8	358.2
359	359.6	4.6
0	.301.0	
1	1.7	
2	3.2	en haut du 180 MHz le Synthetiseur ne lock pas
3	3.6	
4	4.4	
5	5.5	
6	7.2	
7	7.7	∴ un Wavetech (T1437) genere un signal
8	9.2	
9	8-9.7	
10	10.5	
	avec Fo du Lo = 148.525 un Δ de ±3 kHz n'affectent presque pas le reading (±.2°)	avec Fo du Lo = 164.026 un Δ de ±1 kHz affectent jusque'a 10° le changement de reading

APPENDIX 3

TABLE A3

TITLE:	DF INSTRUMENTAL ACCURACY TEST (Final Test) (see graph, Fig. 8.2.7.1, p. 108)
DATE:	January 29, 1982
TEST CARRIED OUT BY:	J. Noiseux, R. Luc
AT:	Bayly, Granby Field Test Site

AZIMUTH	Fo = 127.025 MHz	Fo = 118.025 MHz	Fo = 134.025 MHz
350	349.4	348.6	350.2
0	359.2	357.8	0.4
10	9.9	8.7	10.9
20	20.1	18.8	21.1
30	30.2	27.7	30.4
40	39.9	38.6	40.2
50	50.6	47.4	49.6
60	61.0	58.4	60.3
70	70.8	67.2	70.4
80	80.5	78.5	80.3
90	89.3	87.6	90.6
100	100.7	97.5	100.2
110	110.3	108.5	110.3
120	121.1	117.8	120.2
130	131.3	128.9	130.4
140	141.3	137.8	140.2
150	151.0	148.1	149.9
160	161.1	157.1	159.7
170	170.6	167.2	169.9
180	180.4	177.3	179.3
190	190.8	187.0	189.0
200	200.3	197.5	199.3
210	209.9	206.4	209.0
220	218.4	217.5	218.9
230	227.7	226.1	228.7
240	237.5	237.0	239.1
250	247.5	246.4	249.3
260	258.6	257.1	259.5
270	268.2	266.9	269.8
280	278.7	276.5	279.8
290	288.3	287.0	290.5
300	298.4	296.4	300.2
310	307.8	307.7	310.2
320	318.1	316.6	319.7
330	328.5	328.1	330.2
340	338.1	337.2	339.6
350	348.6	347.7	349.3

POOR

QUALITY

ORIGINAL